An Introduction to

THE STRATIGRAPHY OF EGYPT

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Preface

As every new work is usually parasitic on earlier literature, these notes have benefited much from previous studies carried out on the Phanerozoic stratigraphy of Egypt. Of particular importance are the works of El-Nakkady (1958), Said (1962, 1971, 1981 & 1990), Awad & Said (1966), Klitzsch *et al.* (1984), Hermina *et al.* (1989), Issawi *et al.* (1999) and Issawi (2002). However, a greater part of this synthesis is based on the author's own investigations in the Western and Eastern Deserts and in the Sinai. This is particularly true for the chapters dealing with the Palaeozoic and Mesozoic stratigraphy. I hope that this review will help students in the advanced undergraduate and postgraduate stages in understanding the general stratigraphy of our country.

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BACKGROUND MATERIAL AND FACTUAL CHRONOLOGY

Field study of rocks involves measuring the thicknesses of different rock units, called formations, and plotting their distribution on maps. As the geologist measures the sections and prepares to map the area, he or she must work out the **stratigraphy**, that is, the vertical and lateral relationships of the stratified rocks. The following **stratigraphic principles** help to establish the age relations of formations.

i) Original horizontality: Sediments are normally deposited in horizontal sheets; any dip must have resulted from post depositional folding or tilting. This principle forms the basis for all structural interpretations in regions of sedimentary rocks.

ii) Superposition: Younger sedimentary units overlie older ones; assuming that the layers were not strongly folded or faulted to such a degree that older layers rest above younger ones.

iii) Original lateral continuity: Most formations interrupted by valleys or mountain ranges were originally continuous.

iv) Cross-cutting relationships: Any rock cut by faults or intrusive igneous rocks is older than the fault or intrusion.

v) Fossil succession: Each stratum contains organised fossils peculiar to itself. Older rocks may be expected to contain more primitive fossils than younger rocks.

vi) Sedimentary environments: Sediments accumulate on land in terrestrial environments or on the sea floor in marine environments. Ancient environments are usually recognised by comparing the rocks and fossils with sediments forming today in similar environments.

vii) Facies are different sediment types that replace one another laterally; they have usually accumulated at the same time but in differing environments. Facies are particularly evident where shallow seas and their associated patterns of environments move landward in transgressions or seaward in regressions.

viii) Areas of erosion: Unconformities are gaps in the sedimentary record caused by erosion, rather than sediment deposition; the erosion surface may represent a small or large time gap, and the length of the gap may vary from place to place. Rocks below the unconformity are older than those above.

ix) Bedding: Cross bedding shows the direction of current. In the case of graded bedding, coarser sediments are at the bottom of the stratum and the sediments become finer upwards.

x) The geologic time scale is based on the changing fossil life in sedimentary rocks. It provides a worldwide rather than a local means of dating discoveries. The Phanerozoic Eon is divided into three eras and twelve periods.

Stratigraphic units:

Lithostratigraphic units are designated as formations, members and groups; they are defined solely on the basis of rock type. A **formation** is considered worthy of recognition and naming if its rocks are distinguishable from units above and below, and are thick enough to be plotted on a large scale topographic map. They are the fundamental units used in making geologic maps. Formation names consist of two parts: the first identifies the geographic locality where the rock is well exposed; the second describes the general rock type. The Esna Shale and the Sudr Chalk are typical formation names. Where no single rock type predominates, the second part of the name becomes simply 'Formation" as in the Raha Formation.

Rock units that are distinctive enough to warrant recognition, but are generally too thin to be mapped are called **members** of formations e.g. the Abu Had Member of the Raha Formation. For convenience in small scale mapping, two or more formations may be lumped into a single larger rock unit called a **group**, e.g. the Gharandal Group in the Gulf of Suez region.

A unit formally recognised as a formation in one area may be treated elsewhere as a group or as a member of another formation, without change of name, e.g. Mokattam Formation or Mokattam Group. A unit distinguished only by the taxonomy of its fossils is not a lithostratigraphic but a **biostratigraphic unit.**

Biozones are the fundamental biostratigraphic units and include three principle kinds: Interval Zone, Assemblage Zone and Abundance Zone. The kind of strata that contain the fossils does not enter into the definition. For example, a zone may encompass several units of limestone and shale, or it may fall entirely within a part of a single unit of shale.

Most commonly used is the **Interval Zone** which is the body of strata between two specified documented lowest and/or highest occurrences of single taxa and includes three basic types; Taxon range zone (A) concurrent or partial range zone (B) and the evolutionary or lineage zone (C).

INTRODUCTION

Egypt is situated in the northeastern corner of the African continent and extends beyond the Gulf of Suez and the Suez Canal into the Asian Near East. Its width is about 1226 km and its length from the Mediterranean to the Sudan border is about 1073 km. Egypt's total surface amounts to around 1 million sq. km, occupying nearly one thirtieth of the total area of Africa. Geographically, the country is composed of several distinct regions namely from east to west, the Sinai Peninsula, the Eastern Desert, the Nile Valley & Delta, and the Western Desert. The following paragraphs outline the topographic and geomorphologic features of these regions summarised from SAID (1962).

i) Sinai Peninsula:

Sinai, covering an area of some 61,000 sq. km is triangular in shape and is separated geographically from the Eastern Desert by the Gulf of Suez. The southern part of the Sinai consists of an intricate complex of very rugged mountains formed by igneous and metamorphic rocks. The highest peak is that of Katherina (2641m, a.s.l.). The northern two-thirds of the peninsula comprise a massively developed limestone plateau onlapping the shield in the south known as Badiet El-Tih (Desert of the Wanderings). The higher part of the limestone plateau is called Gabal Egma (1620m, a.s.l.). In the northern part, the regional dip slope is broken up into many large hills, followed northward by a belt of low lands, with high sand dunes along the Mediterranean coast. The principle hill masses include Gabal Yelleg (1090m), Halal (890m) and Maghara (735m). Some of the dunes attain heights of over 100m above sea level. The prevailing drainage system is formed to the north by the Wadi El

Arish (The river of Egypt) with its many affluents. The eastern and western edges are dissected by deep gorges draining into the Gulf of Aqaba and the Gulf of Suez.

ii) Eastern Desert (Arabian Desert):

The Eastern Desert embraces the area between the Gulf of Suez and Red Sea to the east, and the Nile Valley to the west. It consists essentially of a backbone of high and rugged mountains running parallel to, and not far from the coast. These mountains are flanked to the north and west by intensively dissected sedimentary plateaus.

The Red Sea hills do not form a continuous range but rather a series of mountain groups with some conspicuous masses and peaks. Remarkable mountains include Gabal Elba at the southern border (1437m, a.s.l.), Gabal Faraid on the tropic of Cancer (1234 m), the rose-red whaleback of Gabal Hamata (1978 m), G. Nugrus (1505 m), Nugrus sees the small jagged peak of Abu Tiyur near Quseir (1099 m), the little Abu Tiyur looks humbly towards the vast Shayeb (2187 m); the highest hill in the Eastern Desert.

To the north of the igneous mountains are extensive and lofty limestone plateaus of the Southern Galala (1404 m), Northern Galala (1274 m) and G. Ataqa (871 m), separated from one another by broad valleys. To the west of the northern portion of the Red Sea hills and partially separated from them by a wide valley is an extensive limestone plateau extending southwards to near Qena. Further south, the mountains are flanked by a lower over-broadening sandstone plateau extending beyond the Sudan frontier.

The Eastern Desert differs markedly from the Western Desert in that it is intensely dissected by valleys and ravines such as Wadis Tarfa, Assiuti, Qena, Abad, Shait, Kharit and Allaqi. Wadi Qena (200 km in length) follows a direction almost exactly opposite to that of the Nile. The Eastern Desert and the Sinai Peninsula form in essence one and the same geomorphological unit, both areas being related to its geological structures. The northern bulge of the Nubian-Arabian Shield is present in the eastern part of the Eastern Desert and in the southern part of the Sinai Peninsula across the Gulf of Suez, now separated through the development of the East African Rift system. Both the Sinai and the Eastern Desert are characterized by their young geomorphology.

iii) The Nile Valley and the Delta:

The Nile Valley and the Delta occupy the alluvial tract along the terminal 1350 km of the River Nile. The Nile Valley between Wadi Halfa and Kalabsha is bordered by cliffs of sandstone and granite. The construction of the Aswan High Dam rendered large tracts of the Nubian Desert into a vast reservoir of water (Lake Nasser). The total reservoir (at its 180 m a.s.l.) has a surface area of 6,216 km^2, a mean width of 12.5 km and the length of its denderitic shore line is 9,250 km. North of Aswan, the Nile Valley broadens and the flat strips of cultivable land, extending between the river and the cliffs that bound its valley on either side, gradually increase in width northward.

From Aswan cataract to El Sibaiya, the Nile Valley is again cut in the "Nubia Sandstone" with the exception of a stretch 35 km long opposite Kom Ombo plain. In the major part of this stretch, Cretaceous rocks capped by the Eocene rocks border the Nile Valley. At El Sibaiya the "Nubian Sandstone" disappears beneath the Cretaceous sediments and

appears as a fringe to the overlying Eocene formations. Cretaceous rocks extend along the left side of the Nile Valley to south Qena and along the right side to south Nag Hammadi.

From about Qena and Nag Hammadi, rocks of the Eocene formations border the Nile Valley up to the latitude of Cairo. The Eocene cliffs rise to 200-300 m above the alluvial plain on either side at a number of places within that long reach. Along the major northern portion of the Nile Valley, there exist minor deposits of Pliocene and Pleistocene intervening between the valley and the cliffs bordering the valley as well as the wadis draining into it. From Cairo northwards, the Nile Valley opens into the delta. The delta measures about 175 km from south to north and some 220 kms from east to west along its base and cover an area of about 22,000 sq. km of the Quaternary agricultural soil.

The Fayoum Depression covering 1700 sq. km lies west of the Nile Valley and is connected with it by a narrow channel through the desert hills. Its lowest part (about 45 m, b.s.l.) is occupied by the shallow brackish lake Birket Qarun. The existence at various heights above Birket Qarun, of remains of lake beaches containing abundant flint implements and other relics of ancient man proves that the lake must have been of much greater dimensions in Prehistoric times.

iv) Western Desert (Libyan Desert):

The Western Desert stretches from the Nile Valley to the borders of Libya and embraces an area, exclusive of Fayoum, of about 681,000 sq. km, that is, more than two-thirds of the whole area of Egypt. The Western Desert is essentially a plateau desert with vast flat expanses of rocky ground and numerous extensive and deep closed-in depressions. It attains its greatest altitude in the extreme southwestern corner of the country,

where its general plateau character is disturbed by the great mountain mass of G. Oweinat. Northeastward from near G. Oweinat is the extensive sandstone plateau of Gilf El Kebir, nearly 1000 m a.s.l.

A pronounced feature of the Western Desert, obviously due to its arid climate, is the almost complete absence of well marked drainage lines. There are a few gullies draining from its northern edge to the sea, and a few other draining into the Nile Valley. Another feature of the Libyan Desert is the nature and distribution of its water sources. Along the narrow belt of the Mediterranean littoral there are wells and cisterns fed by local rainfall; at the foot of G. Oweinat there are springs fed by the occasional rains which fall on the mountain mass; but the land in between is practically rainless. The oases of Siwa, Bahariya, Kharga and Dakhla owe their habitability to artesian supplies. A third pronounced characteristic of the Western Desert is the occurrence of parallel belts of sand dunes, of immense length and comparatively small breadth running generally in a south-southeasterly direction. One of the most noteworthy of these is the Abu Maharik dune belt which extends for a distance of over 300 km in length.

Because the regional dip of the strata is to the north, cuestas form along formational boundaries. The depressions of Dakhla and Kharga are found at the cuesta formed along the boundary between the "Nubia Sandstone" in the south and the Cretaceous shales and Palaeocene chalk in the north. The Farafra and Bahariya depressions are situated along the Cretaceous-Lower Tertiary boundary while the Siwa and Qattara depressions are located in the shadow of Eocene-Miocene boundary.

Egypt in the framework of global tectonics:

The main global tectonic events that have directly or indirectly affected the geology of Egypt are outlined by MORGAN (1990). The Palaeozoic was a period of relative tectonic stability in the Egyptian geologic record following major Late Precambrian/Early Cambrian Pan African activity.

Palaeozoic rocks in Egypt, as in other parts of North Africa, are predominantly clastic with interfingering calcareous sediments. Lack of fossils in the Lower Palaeozoic portion of this division prevents conclusive dating of most units of this age, and occurrences of Pre-Carboniferous sediments in Egypt are spotty and widely separated. The first well dated and widespread Palaeozoic sediments in Egypt are Carboniferous in age and record another major marine transgression. Two areas of NE Africa showed strong subsidence during the Palaeozoic; the Kufra Basin to the SE of Libya and the Dakhla Basin in Central Egypt. Much of Egypt and adjacent portions of Sudan and Libya were marginal shelf to continental foreland to the Kufra and Dakhla Basins during most of the Palaeozoic.

In summary, the Palaeozoic of Egypt started with the final stages of Pan-African arc accretion to the continental nucleus. Sedimentation for most of the Palaeozoic was controlled by global eustatic sea-level changes with clastic sediments probably derived primarily from Pan African highlands which were probably glaciated for at least some of the first half of the Palaeozoic.

The structural and palaeogeographical evolutions of Egypt and NE Africa since the Cambrian were outlined by KLITZSCH (1988) in the following headlines:

i) Northern dip of the African plate until the Early Carboniferous, which allowed some Palaeozoic transgressions to proceed far south.

ii) Collision of the African plate with northern continents during Mid- or Late Carboniferous time resulting in updoming of large areas of Egypt and consequent erosion and formation of an entirely continental basin south of Egypt.

iii) Disintegration of Pangaea during Jurassic time and establishment of a general northern dip of the African plate which again allowed several transgressions to proceed southward.

iv) Collision of the African plate with Europe and SW Asia during Late Cretaceous and Tertiary times with its structural consequences along the northern edge of the African continent including in addition to the formation of the NE/SW folded mountain belt, the opening of the Red Sea rift and the separation of Arabia from Africa.

Magmatic and tectonic activity from the end of the Palaeozoic continued into the Triassic in Egypt. Predominantly calstic sedimentation continued, primarily in northern Egypt, with cycles consistent with global eustatic sea-level changes at least into the Late Jurassic. Most reconstructions of Pangaea from the Late Permian to Early Jurassic suggest that the eastern Mediterranean was closed during this period with southern Turkey continuous with northern Egypt. If these reconstructions are basically correct, then it seems likely that the eastern Mediterranean basin originated from Early Mesozoic rifting. The Mesozoic sea north of Egypt has been interpreted as part of a southern Neotethyan ocean strand. Thus, as the start of the Mesozoic in Egypt was accompanied by tectonic and magmatic activity continuous from the previous era, tectonic and magmatic activity with a change in sedimentary style continued across the Mesozoic-Cenozoic transition.

The Red Sea-Gulf of Aden rift system has long been recognised as having been formed by the separation of Arabia from Africa and is perhaps the best modern example of continental fragmentation and incipient ocean formation. Early sediments in the rifted zone include marine marls and shales, but as the rising rift margins isolated the Gulf of Suez and Red Sea from the Mediterranean, evaporites were deposited (GARFUNKEL & BARTOV 1977).These basins were reconnected to normal marine conditions at the end of the Miocene with an opening to the Indian Ocean through the Gulf of Aden. Elsewhere in Egypt the rising rift margins acted as a sedimernt source. The ancestral rivers of the Nile appear to have their origin about the same time as the initiation of Red Sea rifting (SAID 1981).

Major structural units of Egypt

From a regional point of view, Egypt forms part of the great African craton which is characterized by a series of Palaeozoic and younger basins that were filled and deformed in subsequent time (AWAD & SAID 1966). Four major structural units can be recognised:

i) Arabo-Nubian Massif:

This is made up of an intericate complex of igneous , metamorphic and sedimentary rocks that belong mostly to the Precambrian and Early Palaeozoic. This is the complex that forms the foundation upon which all later rocks were deposited and which provided the main source of detritus which filled the basins that developed over it.

The Arabo-Nubian Massif forms today the mass of the Red Sea hills in the Eastern Desert and the southern part of the Sinai Peninsula. It also appears as a spur in the cataract region of Aswan and Nuba and in the

southern part of the Western Desert where it extends as isolated outcrops from the Nile near Aswan to Gabal Oweinat in the extreme southwestern corner of Egypt.

ii) Stable Shelf:

Surrounding the Arabo-Nubian Massif is a belt with ill defined boundaries which is characterized by thin continental and epicontinental sediments. These include the widely distributed "Nubia Sandstone" which is capped by shallow marine sediments of the Late Cretaceous-Early Tertiary transgression. The thickness of the sedimentary column next to the Arabian nucleus is in the range of 300-400 m; it increases away from the nucleus until it reaches about 2500 m along the Stable-Unstable Shelf contact.

The Stable Shelf is mildly deformed. True anticlines are not known in this belt. Domes originating epirogenically are large structures that produce diastems or at most unconformities without visible angular discordances. The distribution of the rock facies as well as faunas around these structures is uniform and rock lines are almost time-parallel.

The Stable Shelf deposits are represented first by the orthoquartzites of the "Nubia Formation" exhibiting typical structures and textures of this foreland facies. the sands are well sorted and well rounded. They are cross-bedded; ripple marks are common; conglomerates are thin, oligomictic and localized. A typical succession that overlies the "Nubia Formation" is as follows (from top to base): Mokattam Limestone, Minia Limestone, Thebes Formation (or its equivalent the Farafra Limestone), Esna Shale, Chalk, Dakhla Shale and the Duwi (Phosphate) Formation.

iii) Unstable Shelf:

This shelf is situated north of the Stable Shelf with the transition between the two structural-depositional units following a line approximately set from the Siwa Oasis through Farafra Oasis and Suez into central Sinai. Much of this belt was considered to be typical Stable Shelf, but deep drilling, particularly in the Western Desert, has shown that this large area is divided, beneath its flat cover of later sediments, into a pattern of major palaeogeographic basins and swells. These are indicated mainly by variation in thickness and facies of sediments since most of the area was covered by the principle marine transgressions at least since the Palaeozoic time. The sedimentary column in the Unstable Shelf is composed of the following lithological divisions (AWAD & SAID 1966):

3. Upper Clastic Division: Oligocene-Recent, predominantly clastic but with organogenic limestones.
2. Middle Calcareous Division: from Cenomanian to top of Eocene, predominantly calcareous.
1. Lower Clastic Division: Pre-Cenomanian, predominantly clastic with inter-fingering calcareous sediments.

The formations are gently folded and show signs of lateral stress. Overthrusts are reported from the northern structures. This structural deformation is related to the Laramide phase of the Alpine orogeny. The trend of these old bundles is lightly arcuate to the northeast and referred to as the Syrian Arc.

iv) Gulf of Suez:

The Gulf of Suez is an area of subsidence within the Stable Shelf and the northern part of the Nubian-Arabian Shield. It was intensively

rejuvenated during the rifting phase of the great East African Rift System in Early-Middle Tertiary time. Great accumulations of sediments (more than 10,000 m) from this fast subsiding depression, interrupted at times by a general and regional uplift with subsequent erosion. Its connection with the Mediterranean Sea to the north and with the Red Sea to the south is established during Early Miocene and witnessed with the distribution of Mediterranean fauna from the north as far south as the southern Red Sea.

The presence of three plates is postulated for the north easternmost area of Africa. They are referred to as the Nubian Plate, the Arabian Plate and the Sinai Plate. The relative motion of these plates led to the opening of the Red Sea, the Gulf of Aqaba and, in part, to the Gulf of Suez.

Volcanic activity in Egypt

Different volcanic eruptions took place in Egypt during its post-Cambrian geologic history. According to MENEISY (1990), the Egyptian volcanic rocks of the Palaeozoic and Mesozoic are diversified in their chemical characteristics, size and mode of eruption; whereas the Tertiary and Quaternary volcanics are largely basaltic.

The earliest Palaeozoic igneous activity reflects the emplacement of minor alkaline intrusions and granites as well as "dike swarms" common within basement rocks. Major breaks within the Palaeozoic succession have been reported (ISSAWI & JUX 1982). The breaks reflect uplift and subsidence of Arabo-Nubian Craton, echoing worldwide crustal distribution during the Caledonian and Hercynian orogenies. The Late Carboniferous, Permian and Permo-Triassic vulcanicity is a reflection of land emergence and diastrophism occurring between the Palaeozoic and

the Mesozoic (Hercynian). The Permo-Triassic magmatism is related to the initial breakup of Pangaea and the closure of the Palaeotethys.

Mesozoic volcanic and other magmatic rocks in Egypt are abundant and diversified in size, form and composition (Fig.1). They include basaltic rocks, alkaline ring complexes as well as minor granitic intrusions. The largest Phanerozoic volcanic association in Egypt, namely that of Wadi Natash, southern Eastern Desert, is of Late Cretaceous age. The Late Cretaceous-Early Tertiary magmatism in Egypt is related to the "Laramide" diastrophism or Syrian arcing system, especially noted in northern Sinai and northern Western Desert.

Mid-Tertiary vulcanicity was widespread and was the first to be recognised in Egypt. A number of successive volcanic pulses are indicated starting in the Late Eocene with subsequent extensional phases ranging from Late Oligocene to Middle Miocene (Fig.2). This vulcanicity was intimately associated with the Red Sea opening. Tertiary vulcanicity is uniformly basaltic and widely distributed north of Latitude 28° N and along the Red Sea Coast. Basaltic extrusives cover a large area beneath the Nile Delta and the adjacent parts of the Western Desert. Numerous isolated outcrops also occur along the Fayoum-Abu Roash and Cairo-Suez stretches.

Vulcanicity of Plio-Pleistocene age is the youngest reported volcanic activity dated in Egypt. It is reported in Zabargad (St. John) Island in the Red Sea and in the south Western Desert (MENEISY 1990). The process of sea-floor spreading in the Red Sea continuing up to the present (hot brines and oceanic crust).

Fig.(1): Basaltic sill cutting through Upper Cretaceous rocks in Wadi Matulla, Sinai.

Fig. (2): Miocene basaltic dyke (22 m.y.) cutting across Eocene limestone in Wadi Nukhul, west-central Sinai.

THE PALAEOZOIC

KORA (1984) noticed that although the Palaeozoic rocks are well exposed in numerous localities and many of them were penetrated by drilling in several wells, little has been published on the Palaeozoic of Egypt. This is due not only to the lack of good marker beds and the apparent absence of body fossils in most of the rocks, but also because of their incorrect inclusion in the "Nubian Sandstone" of RÜSSEGGER (1837). However, recently many Egyptian sandstone outcrops previously regarded as Nubia Sandstone are now recognised as separate formations ranging in age from Cambrian to Cretaceous. It is believed therefore that a great part of the so called "Nubian Sandstone", which covers wide areas of inhospitable terranes in the Western and Eastern Deserts and in Sinai, is of Palaeozoic age.

Cambrian age was suggested for beds overlying the Precambrian basement in southwestern Sinai, based on the presence of stromatolites and small archaeocyathids in Abu Durba area (OMARA 1972). Cambrian rocks with trilobites were recorded from the subsurface of the Western Desert in Bahariya-1 (467 m depth; AWAD & SAID 1966) and in North Ghazalat-1 (3723 m depth; ANDRAWIS *et al.* 1983) wells.

Rocks ranging in age between Cambrian and Ordovician and contain ichnofossils as *Cruziana, Rusophycus* and *Skolithos* were recorded from Abu Durba and Um Bogma areas in Sinai (KORA 1984), and could be traced at Wadi Dakhel and Wadi Qena in the Eastern Desert. An Ordovician age was assigned to the subsurface section penetrated by drilling in Gibb Afia-2 well (at 2424 m depth; ANDRAWIS *et al.* 1983) based on a trilobite specimen; *Protocalymene mcallisteri* ROSS.

Palynomophs suggesting a Silurian age were recorded from the subsurface of the extreme western part of the country at a depth of 2902 m in the Foram-1 well (SCHRANK 1987). A Siluro-Devonian foraminiferal assemblage was also recorded at interval 1930-1936 m in Gibb Afia-2 .

Ichnofossils advocating a Devonian age were encountered in east Aswan area and also recorded from Wadi Qena and Gilf Kebir (ISSAWI & JUX 1982; ZAGHLOUL *et al.* 1983). These include *Bifungites* DESIO, *Chondrites* VON STERNBERG, *Planolites* NICHOLSON and others. Late Emsian to Early Givetian spores and acritarchs were recorded from the subsurface of the Western Desert (SCHRANK 1987). Moreover, several plant remains and fossil traces of Devonian-Early Carboniferous age were recorded also from Gilf Kebir-Abu Ras area in southwestern Egypt (KLITZSCH 1990).

The well known Carboniferous exposures of southwestern Sinai have been reviewed recently by many workers (e.g. SOLIMAN 1975; BEYTH 1981 and KORA 1995 & 1998). This interest in the Carboniferous exposures of Sinai was due to the presence of many fossils (corals, brachiopods, molluscans, echinoderms, forams and palynomorphs) in these rocks and also due to their economic importance. Also, Carboniferous palynomorphs were described from the subsurface section penetrated by Wadi Araba borehole (SULTAN 1986) and by Foram-1 in the Western Desert (SCHRANK 1987) which compare well with those described by KORA (1993) from the Um Bogma area in Sinai.

Upper Carboniferous (Westphalian-Stephanian) and Lower Permian rocks exposed on the western side of the Gulf of Suez at Wadi Araba, Abu Darag and the Northern Galala massif were extensively studied (e.g.

ABDALLAH & EL ADINDANI 1965; SAID & EISSA 1969 and KORA & MANSOUR 1992). Equivalent rocks were described from the Eastern Desert in Wadi Dakhel-Wadi Qena stretch (ISSAWI & JUX 1982 and KLITZSCH 1990) which may extend to east Aswan and the Western Desert. Palynomorphs of more or less contemporaneous age were encountered in the subsurface succession penetrated by East Gharib-1 in the Gulf of Suez (SULTAN 1977). A rock stratigraphic classification was suggested for the subsurface Palaeozoic succession of Siwa area; the units include Cambro-Ordovician to Permo-Carboniferous sediments (KEELEY 1989 & 1994)). Palaeozoic basins in northern Egypt are indicated on isopach and facies maps prepared by El GEZEERY *et al.* (1975). Three basins trend generally NNW-SSE were recognised; Gulf of Suez Basin, Northeastern Western Desert Basin and Northwestern Western Desert Basin.

The Palaeozoic rocks in Egypt are overlain by a Permo-Triassic unit; Abu Ras Formation in the Western Desert (ISSAWI & JUX 1982), or Qiseib Formation in the Eastern Desert (ABDALLAH *et al.* 1965) and by the Triassic Budra Formation in Sinai (BEYTH 1981). Rocks of Jurassic or Cretaceous ages may also locally overlie these Palaeozoic rocks.

1. The Palaeozoic outcrops of southwestern Sinai:

The Palaeozoic sedimentary exposures in Um Bogma area are about 370 m thick and are subdivided by KORA (1984) on the basis of their lithological composition and characteristics in the field into six rock units: Sarabit El-Khadim, Abu Hamata, Nasib, Adedia, Um Bogma and Abu Thora Formations. The lower four formations constitute the Lower Sandstone Series of BALL (1916) and are proposed to be of Early Palaeozoic; mostly Cambro-Ordovician age according to their trace fossil

content. Um Bogma and Abu Thora Formations refer to the Middle Carbonate and the Upper Sandstone Series, respectively, of proven Carboniferous age (Fig. 3).

Cambro-Ordovician:

Sarabit El Khadim Formation as used by SOLIMAN & EL FETOUH (1969) is synonymous with the Amudei Shelomo Formation of BEYTH (1981). It overlies unconformably the Precambrian basement rocks and is formed of pebbly pink sandstone and grit with feldspars and rock fragments interbedded with thin siltstone beds. The formation thickens toward the east; from 12 m at Wadi Shallal to 23 m at Gabal Sarabit El Khadim.

Abu Hamata Formation is synonymous with the Timna Formation of BEYTH (1981). In thickness, the formation ranges from 12-18 m. It is composed mainly of laminated multicoloured siltstones, shales and fine sandstones. It overlies conformably Sarabit El Khadim Formation and is characterized by the presence of certain biogenic structures as Cruzianas and some worm burrows. These trace fossils refer to subtidal "shelf" environment of deposition.

Nasib Formation comprises the fine grained sandstone beds that tend to alternate upwards with siltstones and micaceous shale and which overlie conformably the argillaceous beds of Abu Hamata Formation. It ranges from 18-60 m in thickness and is best developed around Bir Nasib. The formation is mostly equivalent to Shehoret Formation of WEISSBROD (1969). The above three rock units are considered members of the **Araba Formation** in other areas of southern Sinai (EL KELANI *et al.* 1999).

Adedia Formation follows conformably and is synonymous with the Netafim Formation. It is most thick (40 m) at Gabal Adedia. It is composed of fine grained, pink brown, cross bedded sandstones. The sandstones are cliff forming and were used as buildingstone for an ancient Egyptian Temple Complex at Gabal Sarabit El Khadim. In other areas of southern Sinai, the formation is replaced by a thicker unit known as the **Naqus Formation** (EL KELANI *et al.* 1999).

A more or less similar Lower Palaeozoic succession is exposed in east-central Sinai at Ras El-Naqab (KORA 1991). These rocks are identical to their counter-parts in west-central Sinai and can be correlated with those exposed in southern Palestine but are far much less thick and poorer in fossils than equivalent strata in southern Jordan and NW Saudi Arabia.

Carboniferous:

Um Bogma Formation overlies unconformably the Adedia Formation. It has a maximum thickness of 41 m at the upper part of Wadi Khaboba and Gabal Nukhul. It decreases to about 20 m at Um Bogma mines and to about 10 m at Gabal Sarabit El Khadim and becomes almost absent further southeast. Um Bogma Formation is composed mostly of grey and pink dolostone. Ferromanganese ore lenses associated with shale beds occur at the base of the formation and were exploited at many localities. The Um Bogma Formation is subdivided by KORA *et al.* (1994) into three members: Um Shebba Member on top, El-Qor Member in the middle, and Ras Samra Member at base (Fig. 4). The middle member is locally richly fossiliferous (Fig.5) with corals; *Syringopora* sp., *Michelinia* sp., *Amplexizaphrentis* spp., etc., brachiopods; *Spirifer striatus, Dictyoclostus semireticulatus,* pelecypods

as *Saharopteria sinaitica,* etc. which confirm an Early Carboniferous "Viséan" age (KORA & JUX 1986).

Abu Thora Formation overlies conformably the Um Bogma Formation and is topped by a basaltic sill or flow of probable Triassic or Jurassic age. It varies in thickness from 60-200 m and could be subdivided informally into two members: Glass-sand member on top, and kaolinitic claystone member at base. The lower member is composed of fine-medium grained sandstones interbedded with kaolinitic clays and carbonaceous shale beds. The kaolin of this member is exploited at Wadi Khaboba, Abu Natash and other localities. The carbonaceous shale grade laterally into local coal seams which contain many continental plant remains; *Lepidodendron, Calamites, Noeggerathia* and microfloral elements assigning a Carboniferous "Viséan-Westphalian" age (Fig. 6). The upper member is formed mainly of clean, snow white, fine grained friable glass sands that are exploited at Um Rodeiyim, El-Qor and Gabal Abu Qafas. The environment of deposition is mostly of aeolian type.

Another Palaeozoic exposure in southwestern Sinai has been described at Abu Durba area (HASSAN 1967). Three rock units have been suggested by SAID (1971): Araba Formation, Naqus Formation and **Abu Durba Formation**. The Araba Formation is intercalated at its base with stromatolitic limestone bed of possible Early Cambrian age (OMARA 1972). On top of the Naqus, a sandstone succession reminiscent to the Abu Thora Formation is recorded (Fig. 6). The Abu Durba Formation (Figs.8 & 9) yielding brachiopods, bryozoans and foraminifers of Late Carboniferous age, could be startigraphically correlated with the Abu Darag exposures (Fig. 7) on the western side of the Gulf (KORA 1989 & 1998).

2. The Palaeozoic outcrops of north Eastern Desert:

Upper Palaeozoic rocks exposed on the western side of the Gulf of Suez were described by ABDALLAH & EL ADINDANI (1965), SAID & EISSA (1969), KLITZSCH (1990) and KORA & MANSOUR (1992). The outcrops are studied at Wadi Araba, northern Wadi Qena , Abu Darag Lighthouse and along the eastern cliffs of the Northern Galala at Wadi Aheimer.

Lithologically, the most abundant strarta are the arenite sandstone which present every gradation of size up to pebble grits and conglomerates. Siltstones and shales are next in abundance. They are grey, greenish, reddish or carbonaceous black. Carbonates are massive-well bedded, light grey-brown and bluish in colour, consisting almost entirely of broken stems of crinoids mingled with corals and valves of brachiopods and bivalves. The carbonate layers are essentially dolomitic in composition.

ABDALLAH & EL-ADINDANI (1965) subdivided these rocks into three formations, from top to base:
- Aheimer Formation,
- Abu Darag Formation, and
- Rod El Hamal Formation.

The three formations have unexposed bases and their exact superposition is therefore unknown. According to SAID & EISSA (1969), these formations seem to be stratigraphically the same in spite of the variations of the foraminiferal faunal assemblage found in each. The exposures range in age from Late Carboniferous to Early Permian.

Rod El Hamal Formation: (100-357 m, Carboniferous)

It is best exposed at the junction of Wadi Araba and Wadi Rod El Hamal and is composed of the following mappable units "members", from base to top:

- Sandstones and shales at the base .... 70m.
- Crinoidal dolomitic limestones and green fossiliferous marls with subordinate sandy silt and quartzitic sandstones. Fossils include *Fenestella carinata, Composita subtilita, Productus semireticulatus, Spirifer mosquensis,* etc.................................. 60m.
- Shales, sandstone and subordinate marls. Fossils include small-sized *Rhynchonellids,* bryozoans, *Bellerophon* sp. etc.. 70m.
- Thick green marl layers interbedded with sandstones and thin fossiliferous dolostone bands. Fossils include rugose corals, brachiopods and crinoids... 45m.
- Shales and sandstones characterized by the presence of coral horizon at its top, brachiopod horizon at its middle and thick shale beds at its base... 112m

Abu Darag Formation: (40-178 m, Late Carboniferous age)

The most complete section of the Abu Darag Formation is exposed at the core and southern flank of the Abu Darag anticlinal structure. In the northern and southern flanks, the formation is overlain by sandy and red beds (Qiseib Formation) which are intercalated with marine thin beds of green marls and yellow hard limestones of Permo-Triassic age.

The Abu Darag Formation could be subdivided into several units characterized by the predominance of continental to semicontinental clastics at its base (30 m), shallow water fossiliferous shales and sandstones at its middle portion (70m) and shale-carbonate deposits at its top. Fossils include bryozoans, bivalves, foraminifers and plant remains.

Aheimer Formation: (60-250m, Late Carboniferous-Early Permian age)

The type locality of this formation is at Wadi Aheimer about 10 kms south of Ain Sukhna. This formation could be subdivided into three members as follows (KORA & MANSOUR 1992).

- The lower member; Coral-bearing shale; mainly shales with highly fossiliferous calcareous beds containing rugose corals, brachiopods bryozoans, etc.. 60 m
- The middle member; Dolostone and sandstone. According to ABDALLAH & EL-ADINDANI (1965) this member contains six crinoidal limestone horizons and five fossiliferous sandy limestone beds. Fossils include brachiopods, crinoids and calcareous forams.. 90 m
- The upper member; Sandstones, shales and siltstones, with arenaceous forams.. 100m

In the north Eastern Desert between Wadi Qena and Wadi Dakhel at the Southern Galala Plateau, Carboniferous strata (40-60m) are designated the Abu Thora Formation (ABDALLAH *et al.* 1992). This unit is conformably overlain by the Lower Cretaceous clastics of the Malha Formation reflecting a wider time gap of the unconformity than that in Sinai (KORA 1998).

3. The Palaeozoic subsurface rocks in north Western Desert:

In the subsurface of the Western Desert, the Palaeozoic rocks, which are mostly of clastic facies, attain more than half the total thickness of the sedimentary succession in Siwa area. They comprise rocks ranging in age from Cambro-Ordovician to the Permo-Carboniferous. Their faunal content helped mainly in dating the Upper Palaeozoic rocks, while the Lower Palaeozoic sediments were found to be poorly fossiliferous. Moreover, these sediments in Siwa area represent, so far, the most

developed and thickest Palaeozoic section ever recorded in Egypt. They are mostly of terrigenous facies, highly oxidized at the base with indications of aerated shallow basins or even terrestrial environment. But, they are of definite marine origin at top. The Palaeozoic rocks of Siwa area are overlain unconformably by the Triassic-Jurassic and Cretaceous rocks.

A formal stratigraphic scheme was proposed by KEELEY (1989 & 1994) for this Palaeozoic succession. Two groups and seven formations span the interval from the Mid-Cambrian to the Early Permian. The resolution between these superficially similar clastic-dominated units is enhanced by the use of palynostratigraphical zonation.

The Siwa Group (Mid-Cambrian-Late Silurian):

This unit is dominated by sand and silt-sized clastic material. Mudstones, conglomerates and dolomites are minor constituents. Variations in bulk lithology enable recognition of the following three constituent formations:

i) Shifa Formation (after the spring Ain Shifa at Siwa): This is a heterogeneous unit (315 m in Siwa-1 well) comprising sandstones with interbedded conglomerates, claystones and skeletal dolomitized carbonates. The varied lithological association and locally high acritarch abundance and diversity levels indicate repeated marine incursions onto a broad alluvial plain.

ii) Kohla Formation (after Kohla area, north of Siwa): This siltstone-dominated unit is very variable in thickness (80-626 m). It is believed to lie unconformably over a glaciated surface forming the top of the Shifa

Formation. A full suite of fluvial, tidal flat and shore face palaeoenvironments can be recognised.

iii) Basur Formation (after the type well El-Basur-1): Sandstones with rare siltstones and extra formational conglomerates characterize this interval. The formation ranges in thickness from about 400-700 m and passes down with apparent conformity into the Kohla Formation. Alluvial fan and braided stream deposits are well represented with thin marginal marine siltstones.

The Faghur Group (Devonian-Early Permian):

A far greater variation in lithology characterizes this group, with limestone and claystone being volumetrically as important as sandstones. Overall, marine influences are far more important. Four formations are recognised:

i) Zeitoun Formation (after the type well Zeitoun-1): In this Devonian unit, claystones are volumetrically the most important lithotype. It is 288 m in the type well. The distribution of facies is complex, but is believed to have resulted from a major rapid marine transgression during the Early Devonian, southward across the Ghazalat Basin, followed by regressive conditions by Late Devonian times.

ii) Desouqy Formation (after the type well El-Desouqy-1): Pale kaolinitic sandstones are the dominant lithological constituents in this Lower Carboniferous (Tournaisian-Early Viséan) unit. The formation ranges from 100 to 362 m in thickness. A suite of continental to shallow marine palaeoenvironments is represented, from high energy fluvial sandstones through shore-face siltstones into pro-delta claystones.

iii) Dhiffah Formation (after the Dhiffah Plateau on the northern Libyan border): This is another very heterogeneous unit (300-400 m thick), being dominated by mud rocks, often calcareous and carbonaceous. Pale oolitic and bioclastic limestones are important interbeds. Foraminiferid fauna from the carbonates supports an Early Viséan to Late Namurian age. The presence of fining-upward cycles points to the activity of transgressive pulses during a period of higher sea levels.

iv) Safi Formation (after the spring Ain es Safi at Siwa):

Sandstones and siltstones are the dominant lithologies in this Upper Carboniferous-Lower Permian unit. It is 155 m thick in Siwa-1 well. The lower contact with the Dhiffah Formation, though abrupt, is not believed to involve a significant break. No stratigraphically conformable succession to the Safi Formation is known due to the effect of "Variscan" erosion.

4. The Palaeozoic outcrops of southwestern Egypt.

The Palaeozoic sediments in the southwestern corner of the Western Desert of Egypt are more continental, sandier, less well developed and contain abundant volcanics and signs of glaciations. The deposits overlie unconformably the Precambrian basement rocks of Gabal Oweinat and stretch northward till Gilf Kebir-Abu Ras Plateau. ISSAWI & JUX (1982) classified the Palaeozoic rocks cropping out in Gilf Kebir-Wadi Malik-Abu Ballas area into the following units:

Ordovician-Silurian:

Naqus Formation is made up of a 10 m thick basal conglomerate followed upwards by about 250 m thick white, coarse sandstones of

fluvio-glacial origin, showing cross bedding and quartz pebbles derived from drip stones.

Devonian:

Wadi Malik Formation; the exposed thickness is 80-100 m, made up predominantly of cross bedded sandstones with minor grit and clay interbeds. The clay includes *Chondrites* sp. The sandstones yield ichnofossils like *Bifungites, Spirophyton*, etc. comparable with the Devonian rocks found in Aswan area.

Carboniferous:

Gilf Formation; the section is composed of 100 m thick exposure of brown-red brown sandstones with planar and trough cross bedding. A 10 m clay bed distinguishes the base of the section, with a 2 m thick basal conglomerate, rich in plant remains and manganese concretions. Among the fossil flora identified are *Stigmaria* sp., *Calamites* sp., fern leaves, etc., typical of Permo-Carboniferous age, and helps in correlating this horizon with the Upper Palaeozoic of Wadi El Dakhel.

KLITZSCH (1983) added that the marine part intercalating the dominantly fluvial to deltaic strata contains trace fossils in the lower 400 m, like *Cruziana accacensis* SEILACHER which is of Silurian age. The western, the central and the northern parts of Abu Ras Plateau consist of strata of Devonian and Carboniferous age. The basal unit of several ten meters thickness is an unfossiliferous cross bedded fluvio-continental sandstones which may be equivalent to the Tadrart Sandstone of Early Devonian age in Libya. The top sequence contains different species of marine trace fossils (SEILACHER 1983) as well as brachiopods (*Camerotoechia* spp.) and plants. The plant remains include

Lepidodendropsis hiermeri, Lepidodendropsis sinaica, Lepidosigillaria intermedia, etc. comparable to the Upper Devonian-Lower Carboniferous flora of the Murzuq Basin in Libya.

ZAGHLOUL *et al.* (1983) reported on the discovery of Palaeozoic rocks (probably Devonian) at Wadi Abu Aggag northeast of Aswan. This is based on the presence of the trace fossil *Bifungites fezzanensis* DESIO in the middle unit of the Nubia Sandstone facies, directly overlying the B horizon oolitic iron ore. ISSAWI & JUX (1982) equated this unit with the Wadi Malik Formation of the Western Desert. The Devonian is overlain by a Carboniferous section with drifted logs of articulate pteridophyta (Asterocalamitaceae) enable correlation with the Gilf Formation.

Palaeozoogeography:

During the Carboniferous, the African plate at its eastern end was uplifted over a large area during the Hercynian structural event. Subsequent marine transgressions affected northern Egypt, probably only marginally. Carboniferous calcareous foraminiferids from Um Bogma and Abu Darag in the Gulf of Suez (KORA 1995) compare with marine microfauna recovered from the Dhiffah Formation in the subsurface of north Western Desert.

Stratigraphic correlations with equivalent units recorded from the southern Peri-Tethyan basins indicate that great areas of North Africa and the Near East were situated near the southern margin of the Tethyan seaway during most of the Late Carboniferous-Early Permian time (KORA 1998). The fossil communities indicate that the Carboniferous succession of Sinai was deposited during a transgressive/regressive cycle of a subtropical epicontinental sea which might have covered the

northern parts of the Eastern and Western Deserts of Egypt, Western Libya and greater areas in north-western Africa (KORA 1995). The swampy-lagoonal and deltaic intervals in the Upper Carboniferous succession can be correlated with equivalent deposits from northern and central Saudi Arabia, Syria and other countries in the Near East (KORA 1998).

Economic aspects of the Palaeozoic deposits:

The Lower Palaeozoic sandstone (400 m) is an excellent reservoir for oil and gas accumulation. In fact it is one of the main pay zones in the Ramadan, Ras Gharib, Hurghada and July oilfields, and is the secondary pay zone at the Bakr oilfield, in the Gulf of Suez Province. In the Western Desert Province, source rocks of appreciable thickness are known in the Devonian-Carboniferous section; composed of grey shales and few sand intercalations. Reservoir rocks are the sands and sandstones that occur throughout the Palaeozoic. Reefs are also sporadically recorded and these are good reservoir rocks. Traps are believed to be structural in nature.

The chief manganese producing district in Egypt is the Um Bogma where ferromanganese ore lenses were exploited in many localities at the base of the Lower Carboniferous dolostones. The ore lenses are associated in some localities with some hydrothermal copper mineralization (Turquoise) in the lower sandstones. Kaolinitic clays are exploited at Wadi Khaboba from the Carboniferous sandstones, which grade laterally into carbonaceous shales and local coal seams; about 60 cm at Wadi Abu Thora, Bedaa, and Allouga. Clean white glass sands are exploited at Um Rodeiyim and El-Qor from the Carboniferous sandstones and may prove to be much more distributed in many other localities in

southern Sinai. Recently, radioactive anomalies are reported in the lower sandstone and the Um Bogma dolostones in the Allouga locality.

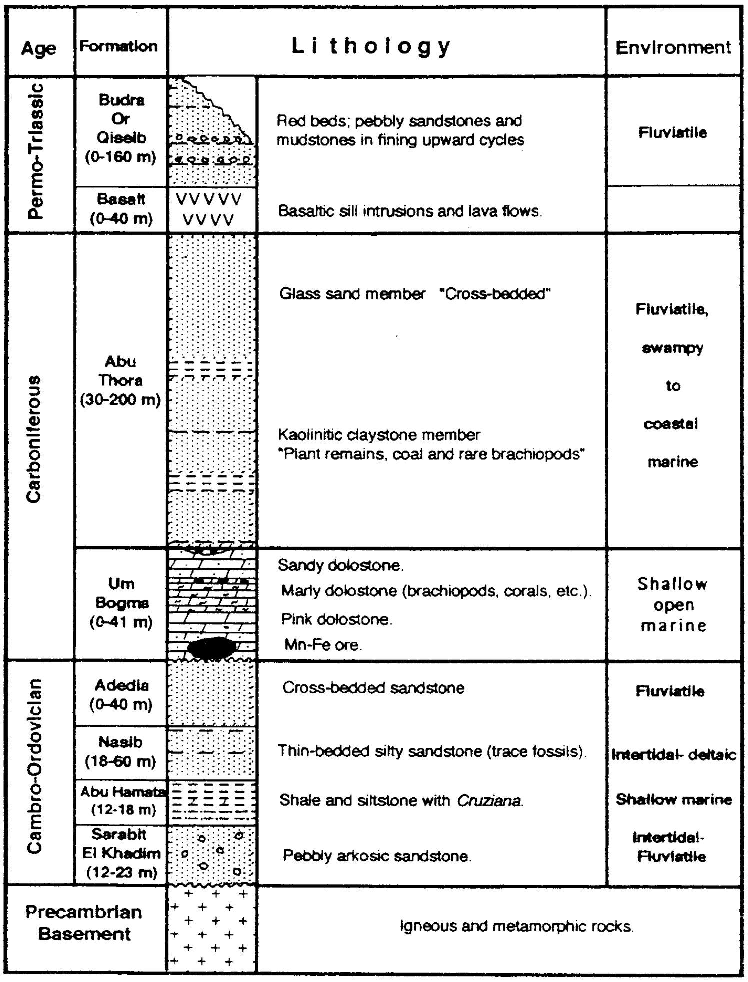

Fig. (3): General lithostratigraphy of the Palaeozoic succession in the Um Bogma area, Sinai (from KORA 1984).

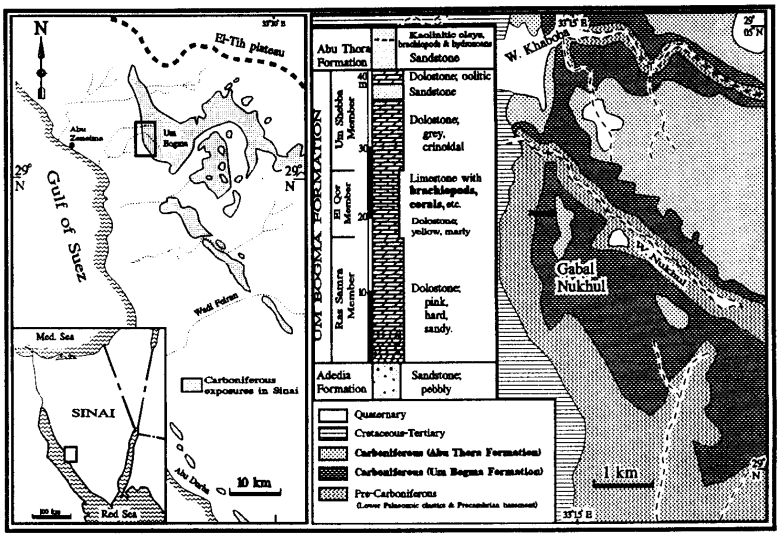

Fig. (4): Carboniferous outcrops of the Um Bogma area, Sinai and the lithostratigraphy of the succession in Gabal Nukhul (from KORA 1995)

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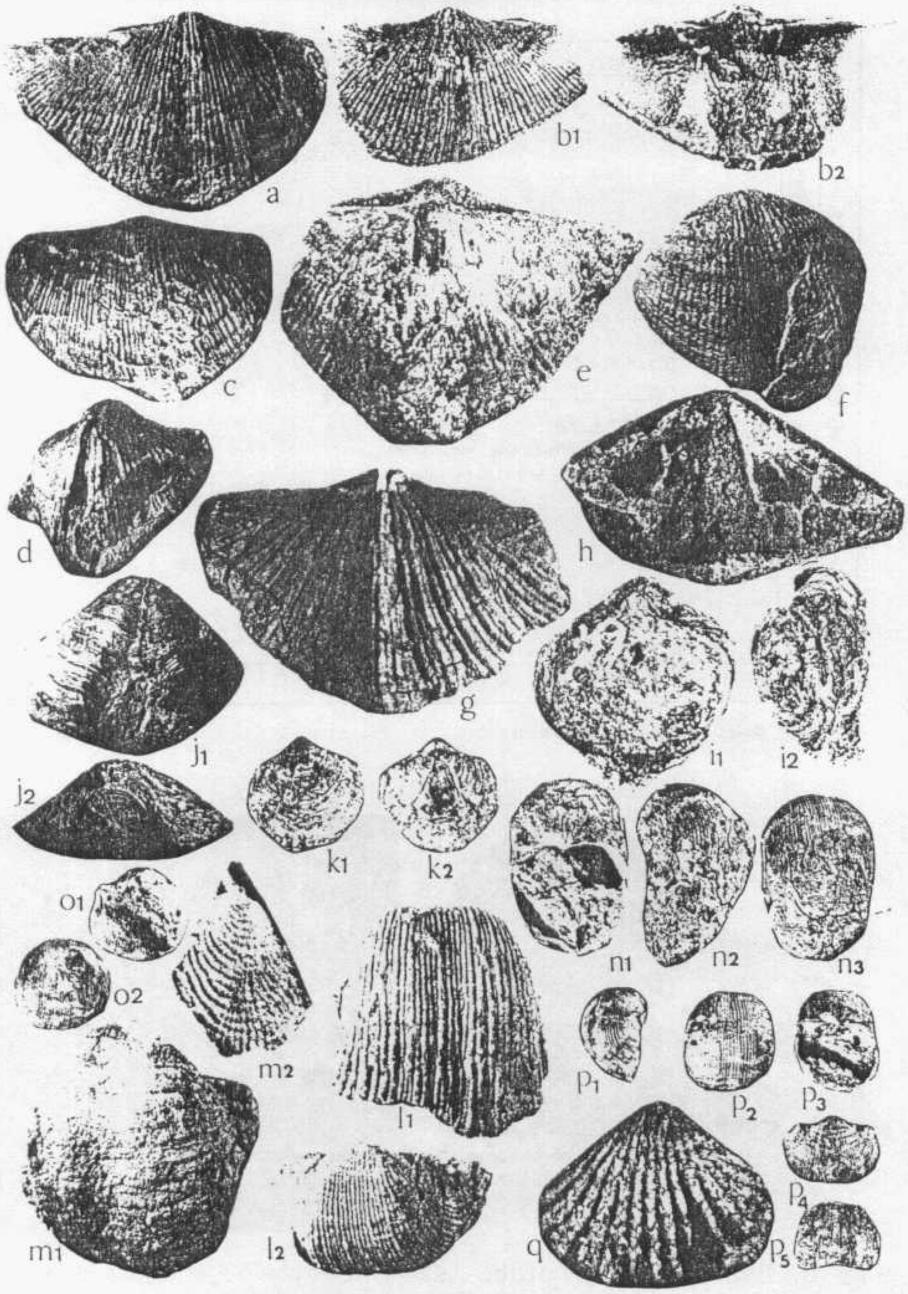
Fig. (5): Brachiopods from the Lower Carboniferous Um Bogma Formation, Gabal Nukhul, Sinai (after KORA 1995); a-d: *Grandispirifer* gr. *mylkensis*, e. *Spirifer striatus*, f. *Spirifer praefascicostatus*, g.*Frechella gwinneriformis*, h. *Syringothyris cuspidata*, i. *Composita ambigua*, j. *Cleiothyridinia deroissyi*, k *Cleiothyridinia fimbriata*, l.*Inflatia inflata*, m. *Dictyoclostus semireticulatus*, n. *Eomarginifera longispina*, o,p. *Marginovatia manardensis*, q. *Pleuropugnoides pleurodon*.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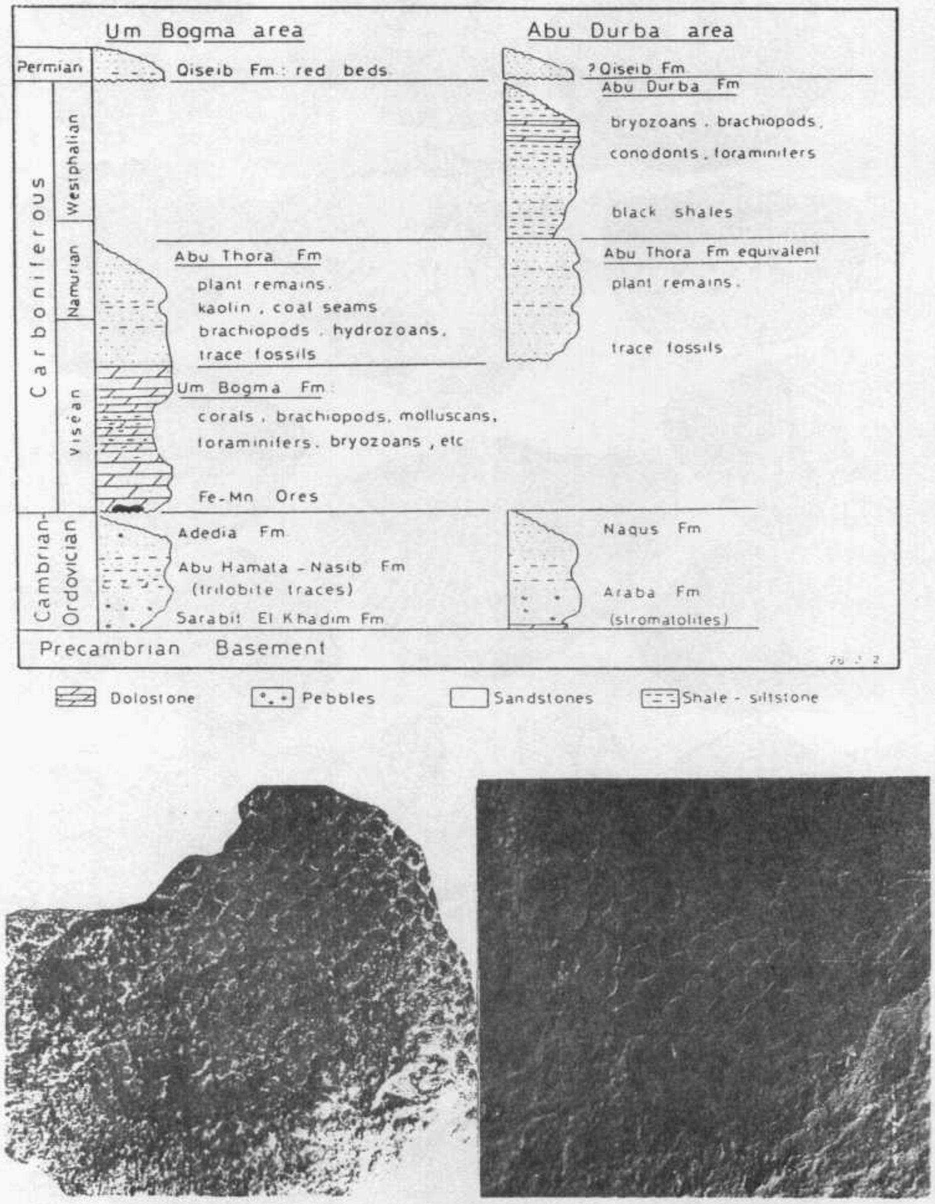

Fig. (6): Lithostratigraphy of the Palaeozoic exposures in Sinai (above), and Carboniferous plant remains (Lepidodendroids) from the Abu Thora Formation (after KORA 1992).

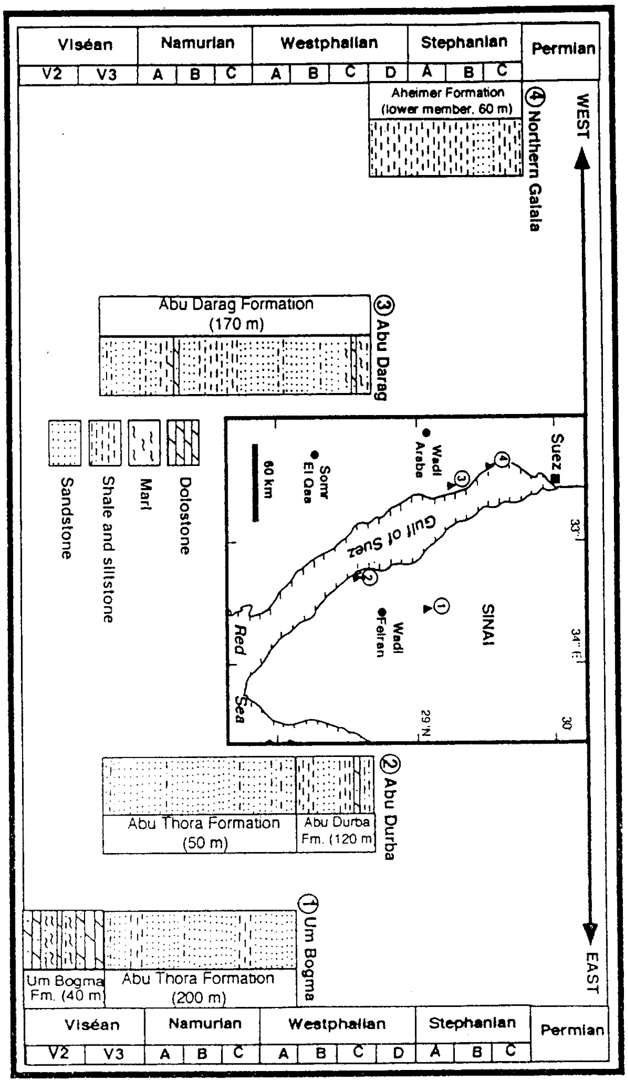

Fig.(7): Rock-stratigraphic relations of the Carboniferous rock units exposed on both sides of the Gulf of Suez (after KORA 1995).

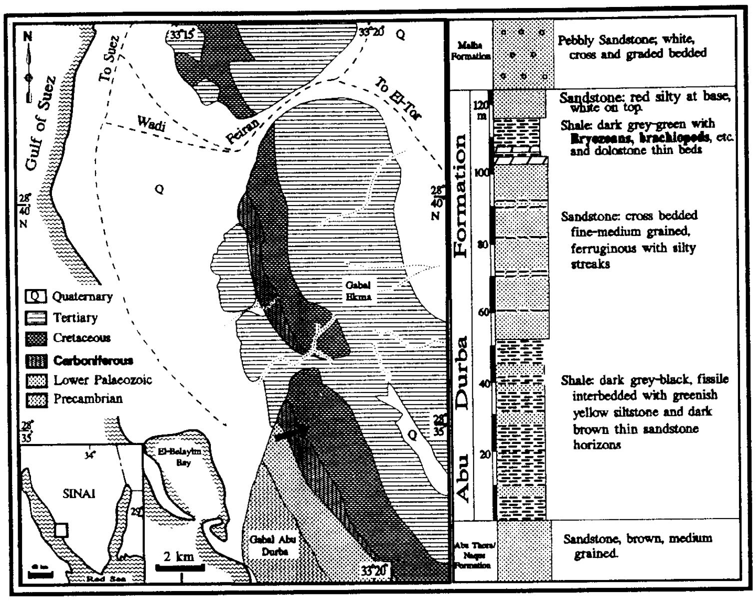

Fig. (8): Carboniferous outcrops of the Abu Durba area, Sinai and the lithostartigraphy of the succession east of El-Belayim Bay (from KORA 1995).

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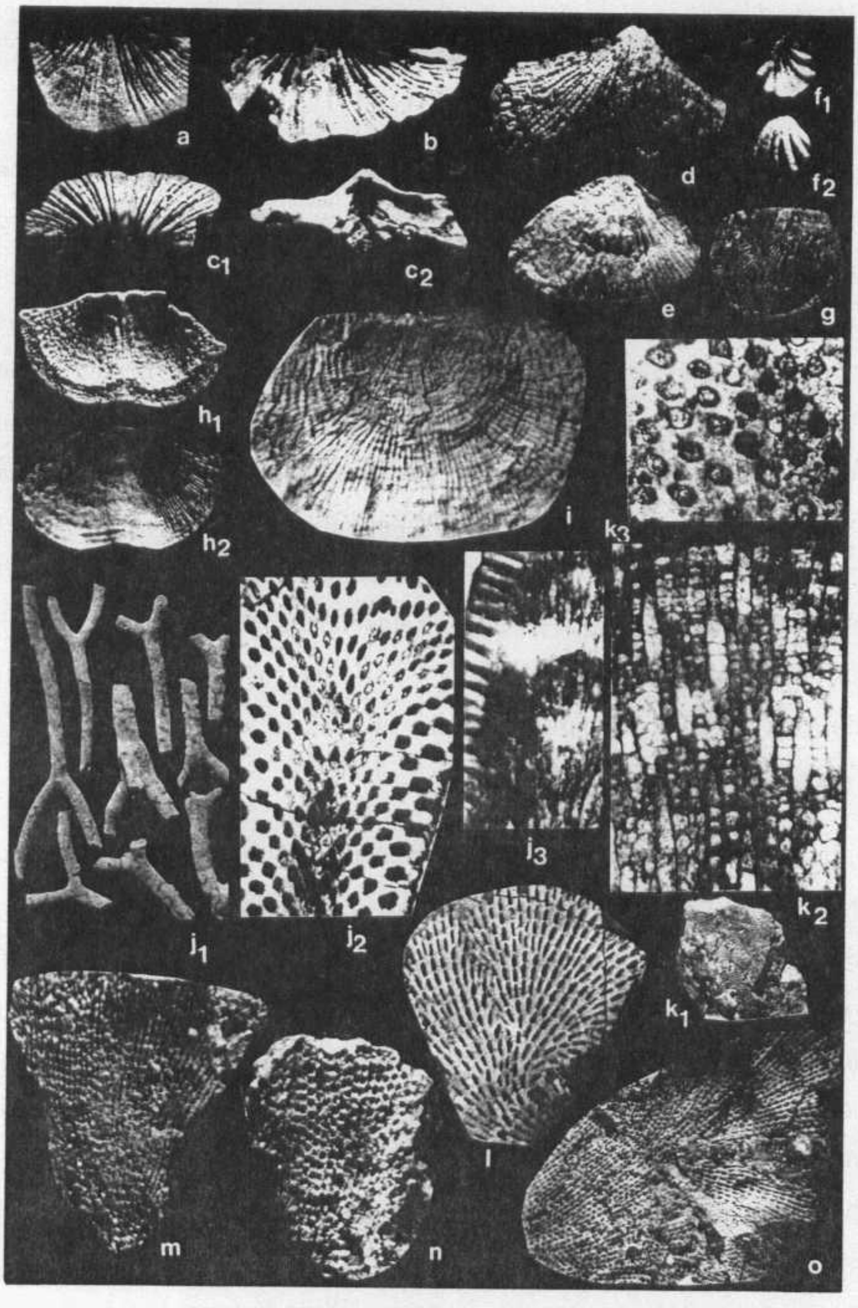
Fig. (9): Brachiopods and bryozoans from the Abu Durba Formation (after KORA 1989). a-c: *Neospirifer cameratus*, d: *Choristitella podolskensis*, e: *Choristites* cf. *mosquensis*, f: *Hustedia* sp., g: *Streptorhynchus crenistria* , h: *Chonetinella* sp., i: *Antiquatonia* sp., j: *Rhombotrypella astragaloides*, k: *Fistulipora* sp., l: *Polypora* sp., m: *Fenestralia* sp., n-o: *Fenestella* spp.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THE MESOZOIC

The distribution of the Mesozoic rocks in Egypt indicates that each of the three systems recognised reflects a distinct palaeogeographic setting (KERDANY & CHERIF 1990). The Triassic seas encroached only over a limited region of the northern part of the country. The Jurassic sea seems to have covered northern Egypt. The Late Cretaceous transgression witnessed one of the widest encroachments of the sea over the country in Phanerozoic times. This extensive distribution of Late Cretaceous sea seems to correspond to a worldwide change in sea level. Mesozoic strata crop out in southern Egypt and in northern Sinai where an almost complete sequence from Triassic to Cretaceous is known. In the northern Western Desert, however, Mesozoic strata are buried beneath younger sediments and are known only from the subsurface.

1) The Permo-Triassic

In the western side of the Gulf of Suez, a clastic section of Permo-Triassic age is known. These rocks are termed **Qiseib Formation** by ABDALLAH *et al.* (1965), and extending from Wadi Araba in the south to north of Wadi Qiseib in Abu Darag area. The Qiseib Formation is lithologically quite distinctive, defined by its strong red, brown and dark brick chocolate colour. It lies over the marine Upper Palaeozoic sandstone. The type locality is at W. Qiseib. It consists of alternations of sandstones, siltstones and shales. These rocks are commonly not fossiliferous and range in size from gravels to fine sand. Gypsum and rock salt are noticed as very thin layers or filling fissures. In this red bed sequence, the shales and clays are red and the sandstones are pale or not red at all. At Wadi Qiseib, the Qiseib Formation attains a thickness of

about 43.5 m, but reaches 80 m along the Suez-Ras Gharib asphalted road on the eastern flanks of the Galala El-Bahariya Plateau.

The Qiseib Formation:

Type locality: Wadi Qiseib, SE Northern Galala.

Thickness: 43-80 m.

Lithology: Red shale-siltstone-sandstone, with a yellow-orange fossiliferous dolostone tongue in the middle at Abu Darag locality.

Boundaries: Overlies fossiliferous marine sandstones of Permian age, underlies Lower Cretaceous Malha Formation.

Extent: Wide areal distribution in the Gulf of Suez region. It is also exposed in the cliffs of Gabal El-Tih between Wadi El-Hommur and Gabal El-Ragaba, and in Wadi Budra in Sinai.

Equivalent units: Budra Formation in Sinai of DRUCKMAN *et al.* (1970); Nubia "A" lower part in the Gulf of Suez wells.

Fossil content and age: Bivalves and gastropods, badly preserved and few plant remains. Permo-Triassic age by its authors, Late Permian age by KORA & MANSOUR (1992), Triassic age by DRUCKMAN *et al.* (1970).

References: ABDALLAH *et al.* (1965) and KORA & MANSOUR (1992).

2) The Triassic exposures in northern Sinai:

These are exposed in northern Sinai at the core of Gabal Araif El-Naga, between Wadi Abu Nusrah and Wadi El-Hadhira. This Gabal (7 x 4 km) is one of the highest structures in Sinai; maximum relief is 934 m a.s.l., simulating a grazing camel in appearance, along one of the more prominent Syrian Arcs. The stratigraphic column of the Gabal ranges

from Middle Triassic to the Tertiary. It is an asymmetrical anticline trending E-NE/W-SW with a fault of the same trend traversing the southern flank of the structure. Marine Middle Triassic beds (Muschelkalk) from this exposure were first described by AWAD (1946). Later, BARTOV *et al.* (1980), ALLAM & KHALIL (1988) and ABED *et al.* (1992) worked on different aspects of the sediments.

SAID (1971) named the Triassic beds exposed in this structure the Arif El-Naga Formation and subdivided them into three members: the "A" or the lower Nubia-type sandstone, the "B" or *Beneckia* beds and the "C" or marine *Ceratites* beds. The "A" and "B" members were given the name Gevanim Formation, and the "C" member the name Saharonim Formation by Israeli workers, who described two other formations, Zafir and Ra'af (Scythian-Anisian) from the subsurface below the "A" beds from Halal well no-1.

Recently, the Geological Survey of Egypt (1993) subdivided the Araif El-Naga succession into three formations from top to bottom as follows:

iii) Mashabba Formation (21 m, Early Liassic):

Ferruginous silt shales alternating with variegated cross bedded sandstones and dolostones with basal pisolitic shale (the so called flint clay). It corresponds to the Ardon Formation of BARTOV *et al.* (1980).

ii) Abu Nusrah Formation (115 m, Ladinian-? Early Carnian):

Fossiliferous hard limestones (dolomitized) marls, shales with a few beds of dolomite and gypseous clays. It corresponds to the Saharonim Formation of the Israeli geologists and was deposited in a shallow marine environment with local hyper saline conditions developing on top of the

succession. It is richly fossiliferous by the ammonites *Paraceratites binodosus*, *Gevanites awadi*, *Beneckia levantina* and *Germanonautilus* sp., etc. together with common brachiopods as *Coenothyris vulgaris* and bivalves like *Myophoria coxi.*

i) Araif El-Naga Formation (70 m, Anisian):

Dark coloured fluvial-fluviomarine quartzitic sandstone and clay beds with some plant imprints and fossil wood, corresponding to the Gevanim Formation of the Israelis.

The marine Triassic transgression followed the Late Palaeozoic Hercynian tectonic event and affected only the structurally lower areas of NE Egypt. During the Middle Triassic, an arm of the sea advanced to the south covering central Sinai and parts of the Gulf of Suez region to the locations of wells Ayun Musa-2, Hamra-1, Abu Hamth-1 and Nekhl-1. The Triassic rocks seem to have been deposited in a shallow shelf which was affected by several regressive cycles. The few occurrences and records of the Triassic in Egypt can give only a vague picture of the palaeogeography of Egypt during the Triassic time.

3) The Jurassic:

Surface Jurassic rocks are known in Egypt at the core of some anticlinal structures in northern Sinai (e.g. Al Maghara & Minsherah), and in the eastern scarps of the Northern Galala massif overlooking the Gulf of Suez (Khashm El-Galala, Ras El Abd and Abu Darag). Probable Jurassic exposures are recently reported from the south-Western Desert in dominantly continental "Nubian" facies sandstones. In the subsurface, several Jurassic occurrences have been recorded mostly in Sinai and northern-Western Desert.

a) The Jurassic outcrops in northern Sinai:

The most complete section of Jurassic exposures in Egypt is that of Gabal Al Maghara where an exposure of about 2000 m thickness is known. It illustrates the transitional zone between the outer shelf edge carbonate series and the predominantly coarse clastic and shale sequences of the inner shelf. Al Maghara represents the first salient massif about 50 km south of Sinai Mediterranean coast, incorporating an area of about 50 km long and 30 km wide, with its longer axis trending NE-SW. It gets its name from Bir El Maghara which is the most important surface water source in the whole region. Shushet El Maghara (735 m) occupies the centre of the region and forms the main watershed.

Structurally, the Maghara area is composed of two NE-SW plunging anticlinal features. The main structure is that of Shushet El-Maghara, the second one is that of Homayir. Also, there are two major curved parallel faults; the Shushet El-Maghara fault zone and the Homayir fault.

AL-FAR (1966) gave a review of the earlier literature and described in detail the lithostratigraphy and structure of Gabal Al-Maghara Jurassic succession as follows:

Masajid Formation (575 m, marine):

- Arousiah Member (443 m thick: Callovian-Oxfordian) made up of the following beds:
  . Dolomitic limestones with corals & echinoids and *Euaspidoceras* fauna.
  . Marls and limestones with chert bands carrying *Perisphinctes birmendorfensis, Arisphenctes* sp.
  . Limestones and marls with *Erymnoceras* sp. and *Quenstedtoceras* sp.
- Kehailia Member: (132 m thick, Bathonian) marly glauconitic

limestone with *Eudesia cardium, Eligmus rollandi, Gryphaea costellata,* and *Micromphalites pustuliformis.*

Safa Formation (215 m, fluviomarine, Bathonian):

- Fluvio-marine current-bedded sands, siltstones and shales with coal seams of economic importance; interbedded shales with marine foraminifera.

Bir Maghara Formation (442 m, marine, Bajocian):

- Bir Member; 216 m thick marls and shales topped by a hard sandstone bed with *Thambites*; lower beds carry *Ermoceras* spp., *Thamboceras* spp.

- Mowerib Member; 133 m thick shales, clays and marls with *Normannites brakenridgei.*
- Mahl Member; 93 m thick hard coralline massive limestone with *Phylloceras* sp.

Shusha Formation (271 m, fluviomarine, Late Liassic):

- Fluviomarine current bedded sandy siltstone

Rajabiah Formation (292 m, marine, Middle Liassic):

- Limestone-marls with abundant algal beds.

Mashabba Formation (100 m, fluviomarine, Early Liassic):

- Sandstones, shales, siltstones and coal seams.

The section is made up of alternating marine shelf deposits (Rajabiah, Bir Maghara and Masajid) and deltaic-fluviomarine sediments (Mashabba, Shusha and Safa). The upper member of Masajid Formation seems to be the most correlatable with other parts outside Sinai. It can be correlated with Kurnub Limestone in Palestine, Hanifa and Tuwaig Limestones in Arabia, and the Glandarienkalk of Syria and Lebanon.

At Gabal Minsherah, northern Sinai, about 80 m Jurassic shales, sandstones and limestones underlying Lower Cretaceous sandstones (FARAG & SHATA 1954) are correlated with Late Bajocian rocks with a typical *Ermoceras* fauna. A reduced thickness (some 22m thick chalky limestone) of the Masajid Formation is recorded at the core of Gabal El-Giddi anticline.

b) The Jurassic outcrops in north Eastern Desert:

Jurassic rocks are exposed at Khashm El-Galala, Ras El Abd, and Abu Darag on the western side of the Gulf of Suez, the best known of which is that of Khashm El-Galala. Here, the Jurassic strata make the lowermost 170 m of this fault-block mountain situated at the northern corner of the North Galala Plateau, in the area opposite Sukhna. At the base of the section, there are about 50 m of fluviatile sandstones and calcareous shales rich in fossil plants of Rhaetic-Infraliassic age that include *Equisites, Phlebopteria* and *Zamites*. Immediately above a plant bed, follow the marine-Jurassic beds. A thick series of marls and thin limestone and sandstone with many brachiopods, pelecypods and rare gastropods of Bathonian age (ARKELL 1956). Shells of *Trigonia pullus, Astarte* sp., *Nucula* sp. etc. occur in thin ferruginous bands. Other slabby limestones are crowded with crushed rhynchonellids, but no ammonites have been observed.

To the south of Khashm El-Galala, a section (100 m) of marine marls and sandstones with Bathonian pelecypods and brachiopods is known. At Abu Darag area, five small discontinuous elliptical occurrences of Jurassic sediments are described by ABDALLAH *et al.* (1965). They are made up of alternating fossilifereous yellow limestones

and argillaceous sandstones and almost exclusively cut by more or less E-W basaltic and doleritic dykes, sills and plugs. Well preserved brachiopods, pelecypods and fragments of ammonites could be collected from these exposures. Most of these five exposures are faulted down and surrounded by the Upper Palaeozoic Abu Darag Formation. The fossils found include: *Thamnasteria* sp., *Rhynchonella orbigni, Rhynchonella asymmetrica, Erymoceras coronatum, Pachyceras* sp., *Nucula variabilis, Pholadomya inornata, Ostrea* sp. and also microfossils suggesting a Middle Callovian-Early Oxfordian age. Also, to the south of Wadi Qiseib, Upper Jurassic rocks were recorded among the relatively low hilly land.

c) Subsurface Jurassic occurrences:

i) Sinai & North Eastern Desert:

Subsurface Jurassic occurrences were reported from El-Khabra well-1 (1936 m thick, Middle-Late Jurassic), Misri well-1 (1818 m, Early-Middle-Late Jurassic) and other wells recently drilled in NE Sinai. In Ayun Musa wells drilled by oil companies for the coal project, the Jurassic successions met with are clastics (85%) with numerous coal seams (=Safa Formation) reaching a thickness of some 955 m directly below the Miocene. In Ataqa well no.1, a clastic section of Jurassic age with some coal (clastics 72%) is reported having a thickness of 580 m. The beds rest below Lower Cretaceous sandstones. Other subsurface occurrences in that area are present in Abu Sultan-2 (244 m), Sukhna-1 (+95 m), Abu Hammad-1 (2374 m), Matulla-1 (118 m) and Baba-1 (370 m) wells. They are recently named Khatatba Formation by oil companies' geologists.

ii) Western Desert:

Subsurface Jurassic successions are known form the following wells; Abu Roash, Khatatba, Ghazalat, Betty, Gibb Afia, Wadi El-Natrun, Faghur and Mamura. Evidence obtained from the stratigraphic column encountered in Khatatba shows that this area remained high for almost the entire length of its geological history except during the Jurassic when it was submerged and received an estimated thickness of 1445 m of sediments (sandstones, shales with limestone interbeds, basalt sheet, quartzites and siltstones). The top of the Jurassic lies only 440 m below the surface. BARAKAT (1982) recognised the following Jurassic units in the subsurface of the Western Desert:

i) Wadi El Natrun Formation (250 m thick in type section):

This formation is restricted to the northeastern corner of the Western Desert where it is composed of dense limestone with green to grey shale interbeds, dolomites and anhydrites at the top and base, respectively. A gradual change to relatively open marine facies is observed northward. The age assigned to the formation is Early to Middle Jurassic. It rests unconformably on Palaeozoic deposits or intertongues with its age equivalent, the Eghei Group, representing the continental facies of the Jurassic south and westward.

ii) Khatatba Formation (590 m thick in type section):

It is made up of greyish green to dark grey carbonaceous shales interbedded with limestones and fine sandstones (=Safa Formation). The porosity of these sands is good (up to 17%), and they can be excellent reservoirs. These sediments represent a marine facies and grade laterally

to the south and west into the Eghei Group. This formation dates to the Middle-Late Jurassic.

iii) Masajid Formation (575 m thick in type section):

It consists of dense limestone, occasionally dolomitized and cherty in parts. Its areal extent is greater than that of the other two formations, reflecting the maximum invasion of the Jurassic sea. The thickest sequence probably underlies the Nile Delta and northern Sinai. A Middle-Late Jurassic age has been assigned to this formation. Furthermore, continental Jurassic occurrences have been recently reported in the south Western Desert. The Jurassic age was assigned to these clastic rocks on palynological evidence.

Jurassic palaeogeography and economic aspects:

The first marine transgression of the Jurassic on the Egyptian shelf was restricted to north Sinai and did not extend beyond the region of the northern basinal area (KERDANY & CHERIF 1990). This occurred during the Liassic as attested by the marine algal limestone and marls of the Rajabiah Formation overlying the fluviomarine Mashabba Formation. This limited Liassic transgression was followed by a regressive phase represented by the fluviomarine Shusha Formation. This, in turn, is followed by a more important transgressive phase during the Bajocian which was responsible for the deposition of the marine carbonates and clastics of the Bir Maghara Formation. This Bajocian transgression reached the northern Western Desert where the clastic to calcareous marine Wadi Natrun Formation was synchronously deposited. Close to the boundary between the Bajocian and the Bathonian, a marked

regression is indicated in Gabal Maghara by the fluviomarine Safa Formation.

A significant transgressive episode is also indicated in the Maghara area in Late Bathonian times. This transgression is characterized by widespread shelf carbonate deposition. It reached the northern part of the Western Desert in Early Callovian time. This episode corresponds to the deposition of the Masajid Formation. The carbonates of this formation continued to be laid down in the Maghara area until the Oxfordian. In post-Oxfordian times, the sea regressed from northern Sinai. The Late Jurassic regression seems to have started earlier in the Western Desert.

The bulk of the strata of three of the Maghara Jurassic formations of AL-FAR (1966) namely; Mashabba, Shusha and Safa formations are of deltaic, lagoonal, swampy and estuarine character. Plant remains are detected in the Mashabba Formation, but no coal seams. In the uppermost beds of the Shusha Formation, coal occurrences are encountered. The Shusha Formation did not yet prove to be of economic importance, but further drilling may prove economic occurrences in this unit. On the other hand, the Bathonian Safa Formation has proved to be the most promising coal-bearing unit in the whole Maghara succession. The coal reserves in this formation are more than 50 million tons in a 30 km^2 area until now and are being under exploitation. Ten coal seams are known, of which two, the main and the upper, are of commercial value. It is a predominantly vitrinite and clarain, long-flamed coal.

4) The Cretaceous

The Cretaceous Period witnessed four transgressive cycles in Egypt (SAID 1990). The Aptian, Cenomanian and Coniacian cycles brought very shallow seas to the passageway between the elevated Nubian and Kufrah massifs. The passageway, which is changed position as the massif eroded, was filled by marginal marine sediments of intertidal, supratidal, estuarine and swamp environments frequently alternating with alluvial sediments. The Campanian-Maastrichtian transgression, on the other hand, brought shallow open marine conditions to large parts of Egypt.

Extent and Facies:

A glance at the geological map of Egypt shows that the Cretaceous rocks cover about 40% of the surface of Egypt. In the Western Desert, they are distributed in the area from as far south as the borders with Sudan to all the Oases Kurkur, Dungul, Kharga, Farafra and Bahariya as well as the isolated structure of Gabal Abu Roash near the Pyramids of Giza. The Cretaceous rocks border both sides of the Nile Valley between Aswan and Qena. In the Eastern Desert, they appear in the area east of Aswan, Wadi Qena, the two Galalas, Gabal Ataqa and Gabal Shabraweet. Along the Red Sea Coast, these rocks outcrop at the Esh Mellaha Range, in the Qusier-Safaga district and as scattered patches near Shalateen. In the Sinai, they cover most of the central plateaus and a great part of the northern structures. The predominance of relatively deeper water conditions in the north is witnessed by the deposition of limestone and chalk throughout the whole Cretaceous times. At the latitude of Qena and further south (Central Egypt), the Cretaceous deposits are represented by alternated limestones, marls, shales and sandstones. In the extreme

southern Egypt, sandstones of "Nubian" facies is the equivalent of the Cretaceous carbonates.

The Lower Cretaceous:

The first major marine transgression in Cretaceous times occurred during the Aptian. It covered the north and south Western Desert as well as the margins of the Arabo-Nubian craton along northern Sinai and the Gulf of Suez region. In northern Sinai, marine Lower Cretaceous strata outcrop in the flanks of the Maghara anticline at Gabal Manzour, Bir Lagama and particularly at the hills of Risan Aneiza. The contact between Jurassic and Cretaceous strata is obscured by wadi fill. Here, the lowermost Cretaceous strata consist of thin cross bedded fine to coarse-grained sandstones and conglomerates (up to 250 m thick). These represent the last pulse of land-derived fluviatile sediments before the oncoming of the major marine transgression of the Aptian; they could be of Barremian age. At Gabals Maghara, Yelleg, Halal and Shabraweet, this lower sequence of continental sediments grades upward into argillaceous clastics interbedded with carbonates deposited under marine to paralic conditions and belonging to the Aptian-Albian.

The Aptian-Albian section overlying the Maghara structure is named the **Risan Aneiza Formation** (SAID 1971). At the type locality on the northern flanks of the structure at Bir Lagama, the formation is 110 m thick or more. The lowest calcareous sandstone bed of the section carries the Aptian *Orbitolina lenticularis* (SAID & BARAKAT 1957). The oolitic ferruginous limestone bed of the upper part of the section carries *Knemiceras* sp., *Douvilleceras mammilatum* and the pectinid *Nithea syriaca* of Early Albian age (LEWY & RAAB 1977)

On the western side of the Gulf of Suez and in central Sinai, the Lower Cretaceous strata are named **Malha Formation** by ABDALLAH *et al.* (1965). The type locality of the formation is Wadi Malha and Wadi Um Galawat at the southeastern cliffs of the Northern Galala and ranges in thickness from 70-130 m, disconformably overlying the Qiseib red beds of Permo-Triassic age. It includes red-grey, fine-coarse grained partly kaolinitic sandstones and siltstones. The formation contains conglomeratic beds in the lower part and stringers of pebbles high in the section. The Malha Formation yields large quantities of kaolin deposits in the form of beds or irregular lenses. It is well exposed along the southern Tih scarp in west-central Sinai. The Malha is believed to be mainly the deposit of rivers which carried clastic materials during a low stand of sea level from the positive areas formed in the Late Jurassic tectonic event. It probably filled low areas in an irregular topography.

The Malha Formation is a poorly fossiliferous unit, the age of which is usually given as Early Cretaceous. In Gabal Musaba Salama area, west-central Sinai, it yielded palynomorphs advocating a "Neocomian" age and fluviatile conditions (KORA & EL-BEIALY 1989). The presence of thin marine fossil-bearing bed of Albian age within the upper part of the formation in Wadi Malha and along the entrance of Wadi Qena, may point to minor marine incursions.

In the subsurface, marine Lower Cretaceous rocks are extensively and thickly developed in the Western Desert. A consistent and well defined *Orbitolina*-bearing bed cuts across this undifferentiated Lower Cretaceous succession. In all wells drilled deep enough to reach this unit, there is always a record of Lower Cretaceous underlying the Cenomanian.

BARAKAT (1982) distinguished two Lower Cretaceous units in the subsurface of the Western Desert:

i) Betty Formation (130 m thick in type section):

It forms the basal Cretaceous unit in the north Western Desert and dates to the Barremian-Neocomian. Lithostratigraphically, it is composed of varicoloured shales and siltstones overlying thick massive sandstones, sub rounded, slightly indurate and poorly porous. In some places poorly preserved pollen and spores are reported indicating a shallow neritic to lagoon environment.

ii) Burg El Arab Formation (900 m thick in type section):

This formation is composed of continental, estuarine lagoonal to marine massive beds of sandstone with shale, limestone and dolomite interbeds. It ranges in age from Albian to Barremian-Neocomian. It is subdivided into four members:

- Kharita Member (Albian),
- Dahab Shale Member or BA-1 marker (Aptian),
- Alamein Dolomite Member (Aptian), and
- Alam El Bueib Member (Barremian-Neocomian).

Among these members, the Alamein Dolomite and the Kharita members are oil payzones in the north Western Desert.

In the southern part of the Western Desert, two Lower Cretaceous rock units were recognised in the former "Nubian Sandstone"

-**The Sabaya Formation** is a brown sandstone succession (100 m thick) with trace fossils and palaeosoils of Albian age (KORA *et al.* 1988)

- **The Abu Ballas Formation** is a white fluviatile sandstone (80 m) with thin *Lingula* Shale marine horizon of Aptian age . It is equivalent to the

Abu Simbel Formation in the Nile Valley and to Selima Formation in northern Sudan (KLITZSCH & LEJAL-NICOL 1984)

The Cenomanian:

The Cenomanian stage is represented in Egypt by deposits of a transgressive sea that progressively advanced to the south (Fig.10). In northern Sinai, these deposits consist almost entirely of carbonates showing a pelagic facies of relatively deep water. Southwards, clastics become increasingly abundant at the expense of carbonates and the total thickness gradually decreases. According to KLITZSCH & HERMINA (1989), two facies were deposited from the Cenomanian transgressive sea in Sinai. The deeper marine facies of the **Halal Formation** in northern Sinai represents a continuous transgressive phase without major regressions. The shallow marine facies of the **Raha** and the **Galala** formations in the Gulf of Suez region reflects a significant influx of detrital materials. Wherever seen; Cenomanian strata lie above the Malha or Risan Aneiza with no break in sedimentation. Episodic sea level fluctuations are indicated in the western side of the Gulf of Suez by rapid facies changes of carbonates alternating with sandstones. In an estuary which pushed to the south, the fluviatile-deltaic-marine sediments of the **Bahariya Formation** were deposited. Further south, in the Dakhla Basin, this unit grades into the **Maghrabi Formation** which reflects lesser marine influence.

At its type locality in Gabal Halal, the **Halal Formation** is 450 m and is made up of carbonate rocks such as limestones, dolostones and marls with minor shales (SAID 1971). At Araif El-Naga, it is 310 m thick. It was named the Hazera Formation (Albian-Cenomanian) by Israeli geologists. Many fossiliferous beds are present and include

echinoids, rudists, oysters and ammonites. The top bed carries the ammonite *Neolobites vibrayeanus*.

The Raha Formation is introduced by GHORAB (1961) for a 70-120 m thick succession in Gabal Raha, western Sinai. It is a heterogeneous unit composed of yellow sandstones, dolostones, limestones, marls and glauconitic shales with oyster beds, gastropods, echinoids, etc. It overlies the Malha Sandstone with seeming conformity, and underlies the richly fossiliferous Cenomanian/Turonian shales of Abu Qada Formation. According to KORA *et al* (1993), the Cenomanian age of the Raha Formation is confirmed based on the presence of the Early Cenomanian echinoid *Hemiaster cubicus* in the lower part and the Late Cenomanian oysters *Ceratostreon flabellatum* and *Ilymatogyra africana* in the upper part (Fig. 11). The Raha Formation is subdivided into a lower Abu Had Member and an upper Mellaha Sand Member as suggested by GHORAB (1961). The Raha Formation is well exposed along the southern Tih scarp. It corresponds to the Hazera Formation described from eastern Sinai and southern Negev by the Israeli workers. It is replaced in northern Sinai by open marine carbonates of the Halal Formation. On the west coast of the Gulf of Suez along the Galala scarps, ABDALLAH & EL-ADINDANI (1965) described a unit similar to the Raha which they named the **Galala Formation** (Fig.12). According to KORA *et al.* (2001), the Galala Formation of the north Eastern Desert is equivalent to the Raha and Abu Qada formations of southern Sinai.

The Maghrabi Formation of BARTHEL & HERMANN-DEGEN (1981) overlies unconformably the Sabaya Formation in south Western Desert. The type section is to the south of the Abu Tartur Plateau (Kharga-Dakhla road) where the formation assumes a thickness of 60 m.

The basal part of the formation consists of flaser bedded sandstones with abundant plant remains (mainly leaves of angiosperms) which is overlain by shale and sandy glauconitic beds carrying abundant pelecypod shells as well as fish teeth of Cenomanian age.

To the north, the Maghrabi Formation changes laterally into the **Bahariya Formation** of El-AKKAD & ISSAWI (1963) in the northern Western Desert. The type section of the Bahariya Formation forms the floor and scarps of the oasis depression around Gabal Dist and has an exposed thickness of more than 300 m underlying El-Hefhuf Formation (SOLIMAN & EL-BADRY 1970 and DOMINIK 1985). The formation includes many fossil-bearing beds; the so called dinosaur bed is followed by sandy thinning upward sequences with numerous paleosols rich in *Ceratostreon flabellatum*, *Exogyra columba* and a host of other characteristic Cenomanian fossils. It was subdivided by DOMINIK (1985) into: El-Heiz Member on top (lagoonal), Gabal Dist Member (estuarine-shallow marine) and Gabal Ghorabi Member at base (fluviatile). It is distributed in the north Western Desert and is oil-bearing in some fields, e.g. Qarun and Salam.

The Turonian:

The Turonian is represented in Sinai and the Gulf of Suez by two distinct units: the Abu Qada (upper part) and the Wata formations. In the north Western Desert, the Turonian deposits are represented by most of the Abu Roash Formation. In southern Egypt, the Taref Sandstone or Formation is the equivalent Turonian unit.

The **Abu Qada Formation** of GHORAB (1961) is coeval with the Ora Shales of the Israeli workers. It is well represented in central Sinai

ranging in thickness from 20-80 m (KORA & GENEDI 1995). The formation is represented by green glauconitic and red fossiliferous shales and marls with yellow limestone intercalations overcrowded with large oysters and ammonites. A Late Cenomanian to Early Turonian age is concluded according to the presence of the Upper Cenomanian oyster: *Exogyra (Costagyra) olisiponensis* in its lower part and many Lower Turonian ammonites including *Vascoceras douvillei* and *Choffaticeras segne* in its upper part (KORA & GENEDI 1995).

The Wata Formation is Late Turonian in age and is coeval with the Gerofit Formation of the Israeli's. It is a hard cliff-forming carbonate unit which overlies conformably the Abu Qada. The Wata is 102 m thick in the type area in Wadi Wata. It is well developed along the Tih scarp measuring 44-70 m between Gabal Gunna and Gabal Dhalal (KORA & GENEDI 1995). It consists essentially of a uniform sequence of well bedded dolomitic limestomes and rudist limestones with minor amounts of chert concretions, marl and shale beds. The upper layers carry the gastropod *Nerinea requieniana* and many rudists including *Biradiolites austinenses, Radiolites peroni,* etc. It is overlain conformably by the shelly dolostones and clastics of the Matulla Formation.

The Turonian is typically developed in Abu Roash area SW of Cairo where Cretaceous rocks crop out as a complex of structural highs (part of the Syrian Arc System) surrounded by topographically low Tertiary sequences. A Turonian tectonic phase led to the formation of a series of half-domes namely El-Gaa, El-Hassana (Protected area) and El-Ghigega. The total thickness of the Turonian succession differs considerably from place to another in the structure, ranging from 100-350 m. The stratigraphy of this sequence has been dealt with in many studies, which

go back to the beginning of this century when BEADNELL (1902) proposed an integrated classification still in use till now including from base to top: Sandstone Series (Cenomanian), Rudist Series-Limestone Series-*Acteonella* Series-Flint Series (Turonian), *Plicatula* Series and Chalk (Senonian).

The *Acteonella* Series is unquestionably of Turonian age. It is currently lumped with the underlying Limestone Series and the overlying Flint Series under this age. It is a fossiliferous shale and limestone unit rich in *Acteonella salomonis, Nerinea requieniana, Durania* spp., etc. (HAMZA 1993). ABDEL-KHALEK *et al.* (1989) correlate between the Abu Roash section and the subsurface Cretaceous sequence in the Western Desert, and lumped all the section underlying the Chalk in one unit; the **Abu Roash Formation** of Norton (1967), while the Chalk has been correlated with the Khoman Formation.

The type section of the **Abu Roash Formation** is Abu Roash-1 well, in the northern part of the Western Desert where a 217 m thick limestone succession is penetrated, intercalating few clastics. It overlies conformably the Bahariya Formation and underlies the Khoman Chalk and is subdivided by Oil Companies into 7 members given the letters from A to G. The Abu Roash "A" is correlated tentatively with the *Plicatula* Series which is equivalent to the Coniacian-Santonian Matulla Formation in the Gulf of Suez . The Abu Roash "B", "C", "D" and "E" members are correlated with the Flint, *Acteonella* , Limestone and Rudist Series while they are equivalent to the Wata Formation in the Gulf of Suez. The Abu Roash "F" and "G" units are equivalent to the Abu Qada and the Raha formations, respectively. The Abu Roash "C" and "E" units are potential reservoir rocks in the Western Desert.

In the Stable Shelf areas of southern Egypt, the Cenomanian Maghrabi Formation is overlain by a continental sandstone sequence known as the **Taref Formation**. The Taref is a thick tabular-planar cross-bedded fluviatile sandstone unit which was deposited during Turonian-Santonian time. This is the typical "Nubian" type sandstone described in the literature. KLITZSCH (1984) recorded marine intercalations with Turonian fossils within this formation between Wadi Qena and Wadi Araba in the Eastern Desert. The Taref is probably coeval with the shallow marine Abu Roash Formation of the northern Western Desert. In the south at Aswan, the section overlying the eroded and leached basement rocks is correlated with the Taref Formation of the Western Desert. It is divided into three members reflecting a transgressive phase between two regressive phases of the Tethys (VAN HOUTEN *et al.* 1984).

The Senonian:

The Senonian deposits in Sinai, Gulf of Suez and the north Eastern Desert are generally marine in nature. During the Coniacian, however, fluvial sediments alternate with the marine deposits of the Gulf of Suez, Southern Galala and north Wadi Qena. In these areas, the Senonian is represented by two units (Fig.13), the Matulla Formation (Coniacian-Santonian) and the Sudr Chalk (Campanian-Maastrichtian). The Campanian beds of the Gulf of Suez form a distinct unit of dark-coloured limestone beds which overlie the Matulla and which are named the "Brown Limestone" by oil geologists.

The relatively soft deposits of the **Matulla Formation** of GHORAB (1961) are conformably underlain by the hard fossiliferous dolostones

and limestones of the Wata Formation and are overlain by hard brown chert bands and white chalky limestones of the Sudr Chalk (Fig.15). In its type locality to the east of Abu Zeneima, the Matulla Formation attains 140 m in thickness and is made up of three units: a lower clastic-dominated member, a middle carbonate-dominated member and an upper shale-dominated member (KORA *et al.* 2003). The upper member contains phosphatic beds with bone fragments. A Coniacian-Santonian age is proposed to the formation according to the presence of the *Metatissotia fourneli* Zone at base and the *Oscillopha dichotoma* Zone (Fig. 14) at top (KORA *et al.* 2002). In central and north Sinai, the clastics of the Matulla Formation are replaced by a carbonate-dominated succession known as the Themed Formation (ZIKO *et al.* 1993). It is coeval with the Zihor Formation of the Israeli geologists. In the west-central Sinai, CHERIF *et al.* (1989) raised the rank of the Matulla to a group including three formations from base to top: Taref Formation, Quseir Variegated Shale and Duwi Formation.

In Gabal Ataqa, the Campanian rests directly over the Cenomanian "Galala Formation". There, the Campanian strata are about 235 m thick and are named the Adabiya Formation (EL-AKKAD & ABDALLAH 1971). The formation is made up entirely of dolomites (quarried) and limestones and is poorly fossiliferous.

The **Sudr Chalk** is a widely distributed rock unit in eastern Egypt. It is characterized by its white colour between the greyish green shales and marls of the Esna Shale above and the yellow sandstones and dolostones of the Matulla Formation below. It measures about 150m in the type locality at Wadi Sudr. At El-Markha Plain along the eastern coast of the Gulf of Suez, it can be subdivided into its two members suggested by

GHORAB (1961). The lower **Markha Chalk Member** is composed of snow white partly silicified chalk intercalated by grey and brown chert concretions and bands with some dolostone and argillaceous limestone streaks. The upper **Abu Zenima Chalk Member** consists of grey, argillaceous and thin bedded soft limestones.

The basal beds of the Markha Chalk Member are highly fossiliferous with *Pycnodonte (Phygraea) vesicularis* which indicates a Campanian age for that member (KORA & GENEDI 1995). The Abu Zenima Chalk Member is of Maastrichtian age (Fig.15) according to the presence of the *Terebratulina gracilis* and *Ventriculites poculum* zones (KORA *et al.* 2002), in addition to the planktonic foraminifers *Globotruncana aegyptiaca* and *Gansserina gansseri*. In eastern and northern Sinai, its upper limit is marked by an angular unconformity separating it from the overlying Esna Shale.

In the north Western Desert, the Chalk deposits are termed **the Khoman Chalk** which reflects a widespread transgression and deepening of the seas over Egypt. Complete sections of the Khoman are found in many of the basinal areas (Abu Gharadig, Um Barka) where sedimentation was continuous, from the Turonian to the Senonian. In these areas, the Khoman is divided into a lower "B" member and an upper "A" member. Outside the basins, it is frequent to see the upper Khoman overlying the eroded Turonian with an angular unconformity. In many instances, the latest Maastrichtian is missing from this sequence indicating a pronounced unconformity. This is probably a reflection of the Late Senonian-Paleocene tectonic movement (Laramide tectonic phase).

In southern Egypt (Stable Shelf area), the Taref Sandstone is capped unconformably by marine variegated shales, named Mut in the Dakhla Basin and **Qusier Variegated Shale** in the Qusier-Safaga district. These vividly coloured shales are believed to have been deposited in supratidal to intertidal flats which were transgressed at times by marine incursions of short duration (KERDANY & CHERIF 1990). The sediments are rich in plant remains, fish teeth (specially the lungfish *Ceratodus*), bone fragments and fresh water gastropods. The variegated shale is 80-100 m thick in the Dakhla Basin and 25-70 m in the Qusier-Safaga district. These variegated shales represent the earliest deposits of the transgressive Campanian Sea.

The marginal marine conditions of the variegated shales were followed by a shallow sea in Late Campanian time in which phosphate beds intercalated with clay, limestone and chert beds were deposited. In the belt which extends from Dakhla Oasis in the west (Abu Tartur Plateau) to Qusier in the east, the phosphate beds are well developed and assume economic importance. They are named **Duwi (Phoshate) or Formation**. To the south of this belt, the phosphate beds do not form an important element in the formation and become indistinguishable from the overlying **Dakhla Shale**. The Late Campanian ammonites: *Libycoceras, Baculites* and *Solenoceras* are usually recorded at the contact. The **Dakhla** (228 m in its type section) is made up of black to dark green shales and marls which carry biostromes of *Exogyra overwegi* of Maastrichtian age. These are followed upward by a thick shale section with minor calcareous sandstone beds carrying *Cardita libyca* of Early Paleocene age.

Along Darb El-Arbain, in the southern rim of the Dakhla Basin, the variegated shales, Duwi and Dakhla formations changed laterally into a sandy facies lumped together in a unit named **the Kiseiba Formation**. Toward the north, in the Farafra Basin, the Maastrichtian shaly facies of the Dakhla changed into a chalky facies classified with the north Western Desert Khoman Chalk.

Economic aspects of the Cretaceous deposits:

- The Cretaceous sediments are important source and reservoir rocks for oil and gas in the Gulf of Suez and the north Western Desert petroliferous provinces.
- The Cretaceous clastics produced huge quantities of kaolinitic clays used for ceramic, white cement, rubber, paper and other industries.
- The Cretaceous phosphates are produced from the Duwi Formation in the Nile Valley, Abu Tartur Plateau and in the Qusier-Safaga district.
- Aswan oolitic iron ores were once exploited from the Cretaceous clastics NE of Aswan.
- Cretaceous carbonates (chalks, limestones and dolostones) are quarried and used in several industries. They are used as building stones and are also crushed and used as a sub-base in asphalted roads.

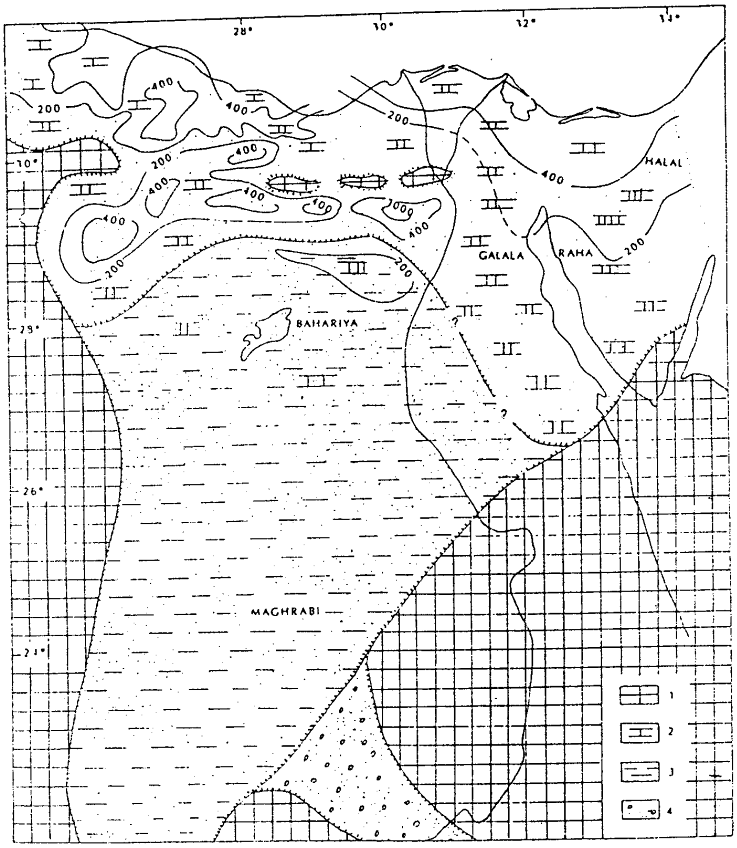


Fig. (10): Egypt during Cenomanian time. 1: positive areas, 2: open marine sediments, 3: estuarine deposits, 4: fluvial deposits (from SAID 1990).

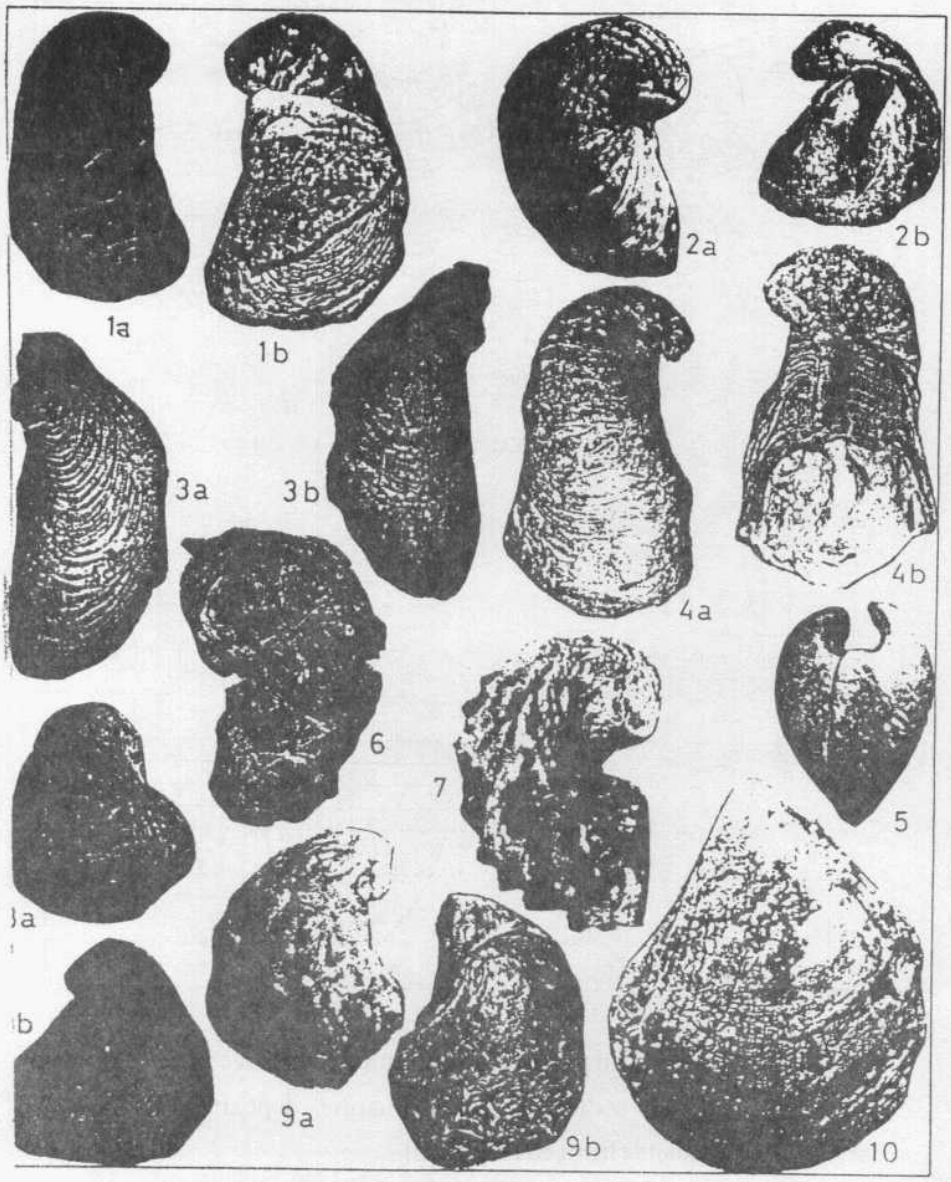


Fig. (11): Cenomanian bivalves from Wadi Feiran (from KORA *et al.* 1993). 1: *Ilymatogyra africana*, 2: *Rhynchostreon suborbiculatum*, 3: *Gyrostrea delettrei*, 4: *Texigryphaea navia*, 5: *Isocardia simplex*, 6-7: *Ceratostreon flabellatum*, 8: *Exogyra columbella*, 9: *Exogyra* (*Costagyra*) *olisiponensis*, 10: *Lima tihensis*.

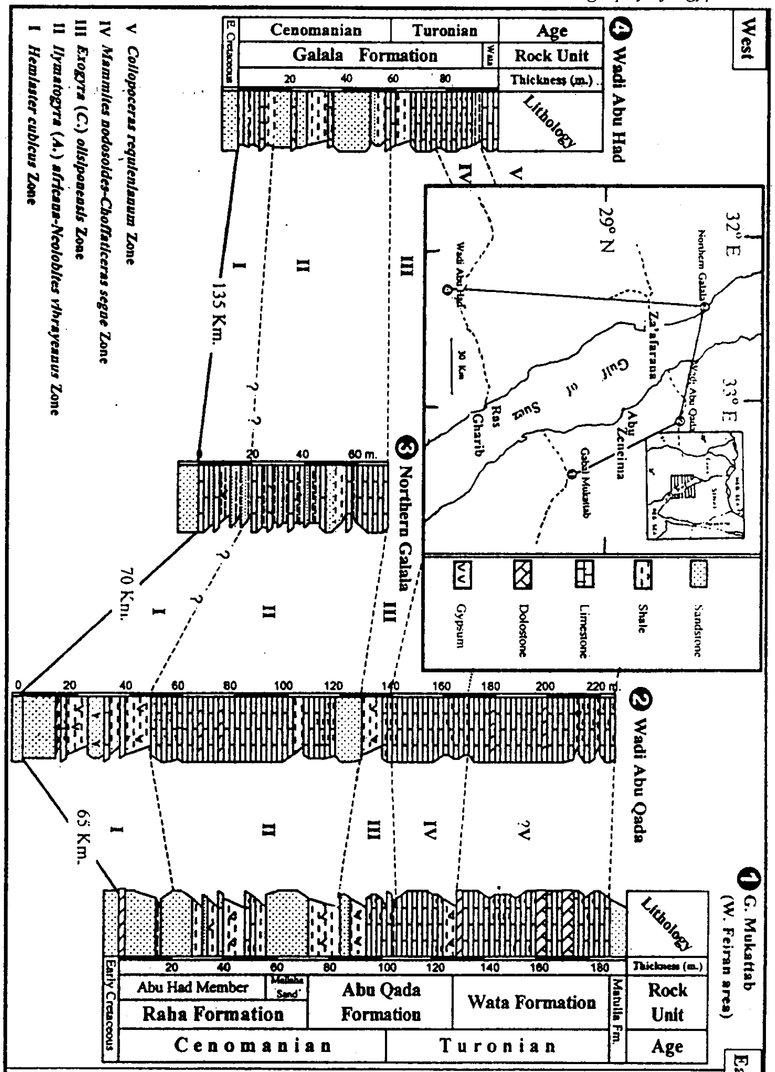


Fig. (12): Distribution of the recognised biozones in the Cenomanian-Turonian succession in the Gulf of Suez region by KORA *et al.* (2001).

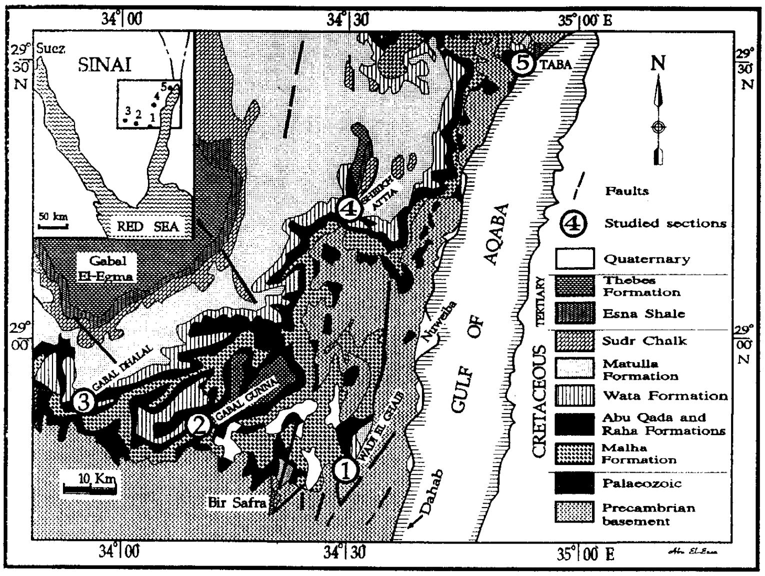


Fig. (13): Simplified outcrop pattern in east-central Sinai (from KORA & GENEDI 1995).

Fig. (14): Senonian oysters from Sinai (Bar scale=10mm), after KORA *et al.* (2002).

1. *Oscillopha dichotoma*, Matulla Formation, Wadi Sudr.
2. *Pycnodonte* (*Phygraea*) *flicke*, Matulla Formation, Wadi Sudr.
3. *Pycnodonte* (*Phygraea*) *proboscideum*, Matulla Fm., W.Sudr.

4,5. *Pycnodonte* (*Phygraea*) *vesicularis*, Sudr Chalk, W.Abu Qada.

6. *Pycnodonte* (*Costeina*) *costei*, Matulla Fm., Wadi Sudr.
7. *Curvostrea heinzi*, Matulla Formation, Wadi Abu Qada.
8. *Nicaisolopha nicaisei*, Matulla Formation, Wadi Sudr.
9. *Nicaisolopha lyonsi*, Matulla Formation, Wadi Sudr.
10. *Flemingostrea boucheroni*, Matulla Formation, Wadi Matulla.

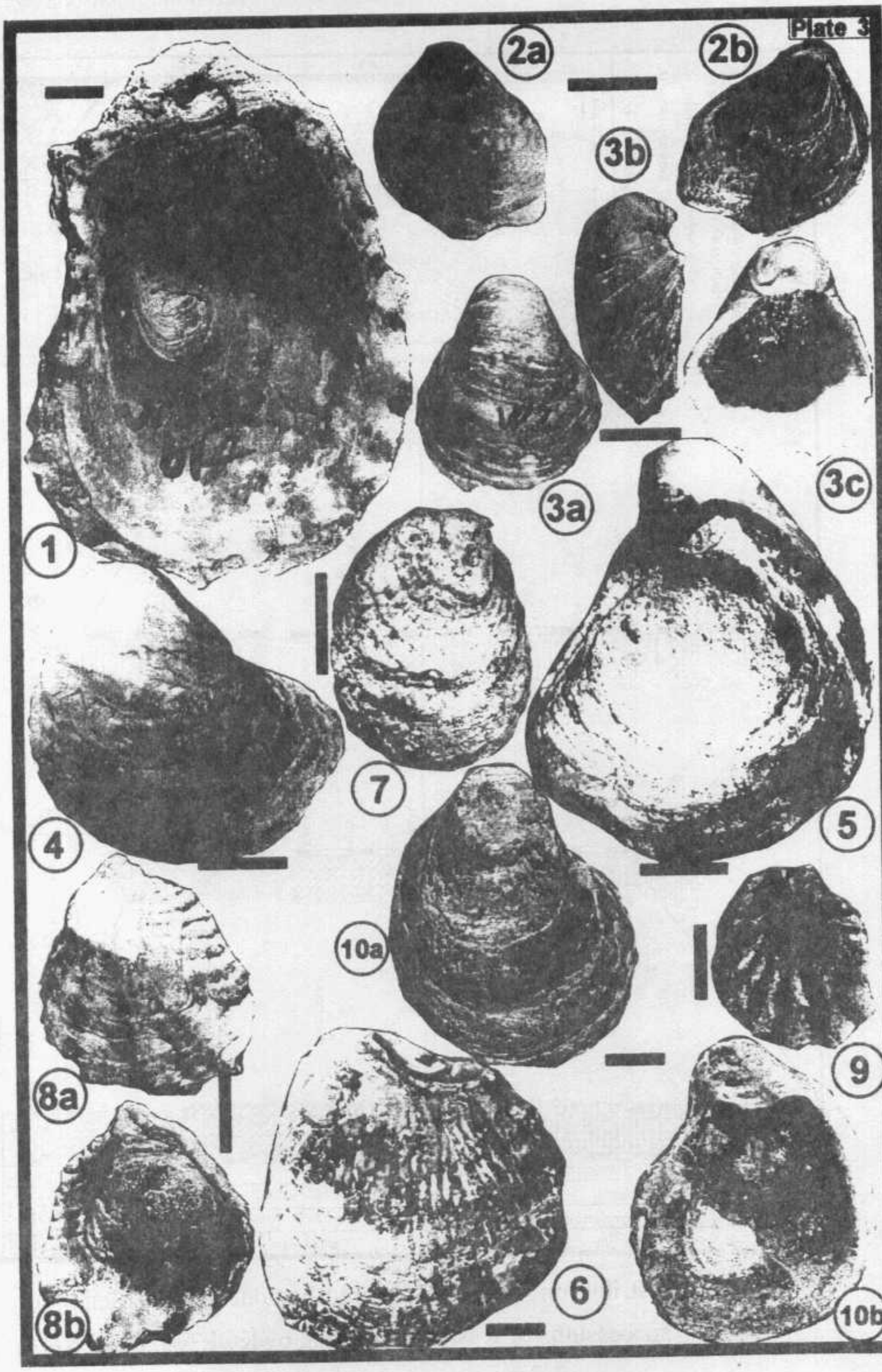


Plate 3
1
2a
2b
3a
3b
3c
4
5
6
7
8a
8b
9
10a
10b

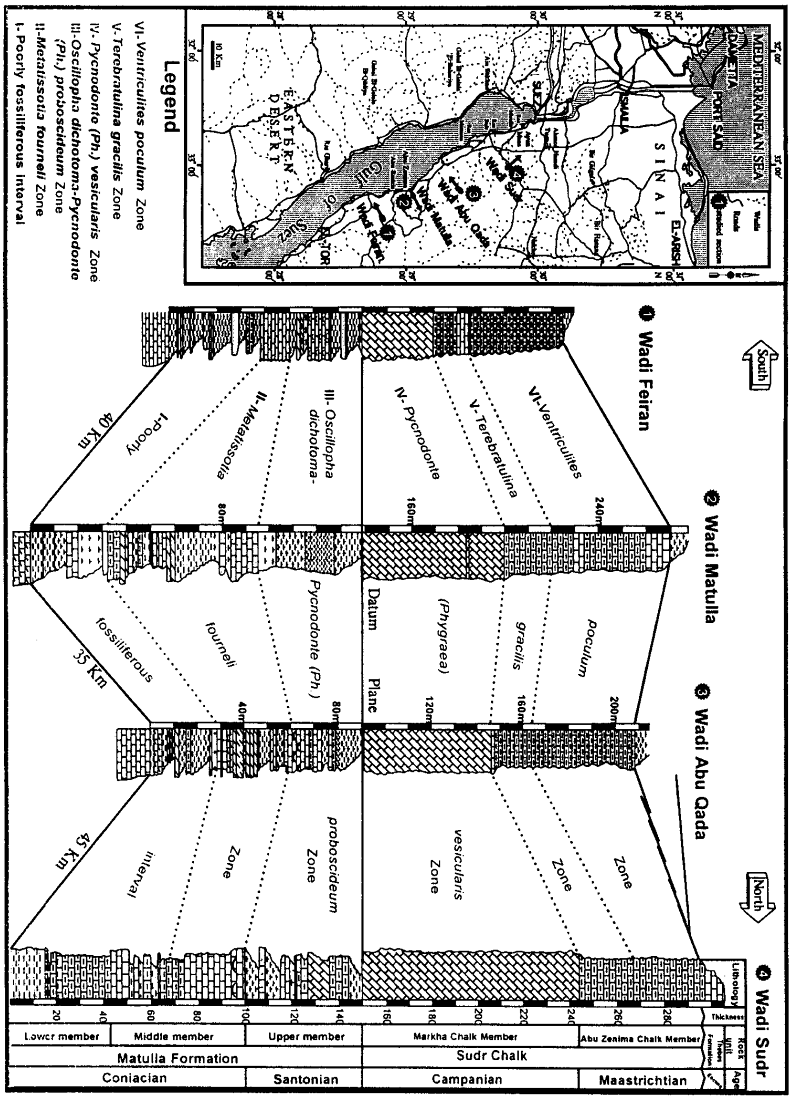


Fig.(15): Distribution of the recognised biozones in the Senonian successions of west-central Sinai by KORA *et al.* (2002).

THE CENOZOIC

In Egypt, the Paleogene and the Neogene are separated from one another by dramatic events which changed the landscape of Egypt, initiated the process of formation of the Red Sea Rift, raised mountains and activated volcanoes. The sediments of these two sub periods cover large areas of Egypt.

The Paleogene

Paleogene rocks lie unconformable over Upper Cretaceous or older rocks in most areas of Egypt. The nature of this contact differs in the two major tectonic provinces of Egypt, the Stable and the Unstable Shelves. The transitions from the Cretaceous to the Paleogene in the south Stable Shelf areas was not accompanied by intense tectonic disturbances; the deposits of the Paleogene lie disconformably over the Cretaceous and are separated from it by thin intraformational conglomerate carrying reworked Upper Cretaceous fossils (SAID 1990). In these areas, the Cretaceous/Paleogene boundary lies within the Dakhla Shale, a mappable unit of great areal extent in southern Egypt.

In the north Unstable Shelf areas of Egypt, the Upper Cretaceous and Lower Tertiary rocks exhibit varied relationships. These relationships seem to have been governed by the palaeorelief inherited from the Late Cretaceous tectonics which affected the Unstable Shelf and upon which the Lower Tertiary sediments were deposited. In the synclinal areas of this palaeorelief more complete sections of the Upper Cretaceous and Lower Tertiary are found. Here the hiatus is relatively small and the boundary lies either on top of the Sudr Chalk or else cuts across the overlying Esna Shale (SAID 1990). In the more positive areas of this palaeorelief great

breaks are known as a result of the non-deposition of total systems or stages (e.g. the north eastern part of the Bahariya Oasis).

The Paleocene and Eocene

Paleocene and Eocene outcrops are usually associated with each other covering more than 21% of the surface area of Egypt. They are well exposed in the Nile Valley and bordering areas in the Western and Eastern Deserts, forming plateaus and building mountain scarps on both sides of the Gulf of Suez, central and northern Sinai. They are mostly represented by open marine sediments of carbonates, marls and shales.

A typical **Paleocene** section of the Stable Shelf is that of Gabal Awaina, a 450 m high outlier lying about 8.5 km to the northeast of the Sebaiya railway station. This hill is the type locality of the **Esna Shale** rock unit. The Gabal Awaina section is made up primarily of shales interrupted by a middle carbonate bed named **Tarawan Chalk.** Toward the top bioclastic carbonates characterize the transitional layers to the massive limestone beds of the Lower Eocene Thebes Formation. The whole succession rests with seeming conformity on the oyster limestone and associated phosphatic beds of the Duwi Formation. In the type locality, the **Esna Shale** is a laminated grey green clay-shale unit (104 m thick) overlying the Tarawan Chalk and underlying the Lower Eocene limestone with chert bands of the Thebes Formation. It ranges in age from the Thanetian to the Ypresian according to its planktonic foraminiferal and calcareous nannoplankton content (SAID 1990). The Paleocene/Eocene boundary section was chosen at Dababiya south of Luxor within the upper part of the Esna Shale.

The Paleocene deposits of the Stable Shelf areas of Egypt are of great areal extent and are found in areas as far apart as Dakhla and Qusier. In

this stretch they are represented by the upper part of the Dakhla Shale, the Tarawan Chalk and the lower part of the Esna Shale. Along Darb El-Arbain, the Tarawan Chalk is replaced by a brownish yellow limestone unit with clastic interbeds named **Kurkur Formation** which is followed in turn by a sequence of shale with carbonate and marl intercalations referred to as the **Garra Formation** (ISSAWI 1971).

Toward the north in the Unstable Shelf areas, the lower shales of the Dakhla Formation change laterally into chalk: the Khoman in the Western Desert and the Sudr in the Eastern Desert and Sinai. The upper part of the Dakhla, the Tarawan and the Esna, which are of Paleocene to Early Eocene age in the Stable Shelf areas, are represented by the Esna Shale in the Unstable Shelf areas. This unit is of wide extent and is distinct by virtue of its position between two mappable carbonate units: the Sudr below and the Thebes above. In many areas in the north, the Esna Shale is cut across by a characteristic limestone unit reminiscent of the Tarawan Chalk of the Stable Shelf area (e.g. west-central Sinai).

No overall classification of the **Eocene** rocks of Egypt is universally accepted. Most classifications start from Zittel's major divisions: the Libysche and Mokattamstufe to which SAID (1960) gave the formal names Libya and Mokattam Groups, respectively. The Libya Group was subdivided into the Esna, Thebes (= Zittel's Lower Libyan) and Minia (Zittel's Upper Libyan) formations. The name Mokattam Formation was retained from Zittel's Lower Mokattam and the name Maadi Formation was coined to cover Zittel's Upper Mokattam. Subsequent workers accepted this framewark, elaborating and refining on it (e.g. BOUKHARY & ABDEL MALIK 1983, STROUGO 1986, etc.). Many

new formational names were suggested to differentiate certain facies or to designate rock types.

SAID (1990) subdivided the Eocene deposits into the following major rock units, from top to bottom:

- **Maadi Group** comprising from top to bottom the Wadi Hof, Wadi Garawi and Qurn Formations and their equivalents.
- **Mokattam Group** divided into a lower Mokattam Subgroup comprising the *Nummulites gizehensis* - bearing units of the Cairo area and their equivalents in other parts of Egypt, and an upper Observatory Subgroup for the carbonate sections of the Cairo area and their equivalents in other parts of Egypt.
- **Minia Formation**
- **Thebes Group** comprising the Thebes Formation of the Stable Shelf areas and its equivalents in other parts of Egypt.
- **Esna Formation** (top part) and its equivalents.

The Thebes Formation

It was named by SAID (1960) for the scarp-building limestone unit of southern Egypt and central Sinai. The type section of this formation is at Gabal Gurnah, Luxor behind the famous temple of Deir El-Bahari where it lies disconformably above the Esna Shale. The section is 290 m thick and is divided into three members. The lower member (135 m thick) is made up of thin alternating beds of indurated limestones and friable chalk with scattered or banded nodules of chert; the upper part of this member is marly and yielding the characteristic pelecypod *Lucina (Anodontia) thebaica.*

The middle member (125 m thick) is made up mainly of thinly bedded fossiliferous chalk beds with nodular limestone interbeds, *Nummulites* and *Operculina* banks with numerous echinoids and pelecypods. The upper member (30 m thick) is made up of reworked shell hash; oysters, echinoids and alveolines are common. It is 95 m thick in Gabal Shaghab. The age of the Thebes Formation is Early Eocene belonging to the planktonic foraminiferal zones P8 & P9: *Morozovella aragonensis* and *Acarinina pentacamerata.*

The Thebes is widely distributed. It makes the tablelands of the middle latitudes of Egypt, the bulk of the Egma plateau in Sinai and the scarps of the mountains of the Gulf of Suez. In places, the Thebes is replaced laterally or overlapped by rock units which differ in appearance due to the predominance of one or more lithologies, to which several local names have been recently coined including the Rufuf Formation, the Farafra Limestone, Dungul Formation, Drunka Formation, the Egma Limestone and the Serai Limestone.

The Minia Formation

The name Minia Formation was proposed by SAID (1960) to designate the alveolinid snow white limestones (110 m thick) which underlie the first *gizehensis*-bearing beds. It follows on top of the Thebes Formation in the Nile Valley with seeming conformity. The type section is at Zawiet Saada, opposite Minia. Like the Thebes, the Minia is mainly made up of carbonates of different composition, texture and structure, attesting to the varied environments in which these primarily shallow water sediments were deposited. The lower bed is exceptionally rich in *Nummulites* spp. and other reefal forms (corals, *Orbitolites, Alveolina* spp, etc...). The bed is massive and forms a characteristic partly mappable ledge to which the

name Maabda Member was given. The Minia Formation was originally given early Middle Eocene (Lutetian) age. It has a restricted areal distribution and is known only in the Nile Valley. Toward the west in the area of the Bahariya Oasis, the Minia becomes considerably thinner and is replaced by a dark grey to pink sequence of dolomitic limestone beds (29 m thick) known as the **Naqb Formation.** The Naqb is a sublittoral deposit of limited areal extension in the northern part of the Bahariya Oasis. The iron ore deposits of the Bahariya Oasis are layered lenticular bodies interfingering the Naqb.

The Mokattam Group

According to SAID (1990), the Mokattam Group comprises the section originally described by Zittel (1883) under the term Mokattamstufe in its type locality Gabal Mokattam to the east of Cairo. Here the upper limit of the Mokattam Group is clear and is marked by change of the facies from solid white to yellowish carbonates to more friable yellow to brown marls and sandy limestone of the Maadi Group. The contact between the Mokattam and the underlying Minia is exposed to the south in the section facing the village of Sawada, Minia (STROUGO 1986).

The Mokattam Group comprises a number of units which could be broadly classified into a lower bedded carbonate unit carrying in profusion large *Nummulites* of the *gizehensis* type and to which the name Mokattam Subgroup is given and an upper solid and massive carbonate unit with minor occurrences of the large nummulites. To this latter unit the name Observatory was suggested by STROUGO & BOUKHARY (1987).

The Mokattam Subgroup

The oldest unit of the Mokattam Subgroup is exposed at the village of Sawada where a bedded limestone unit crops out above the Minia Formation. This unit (160 m thick), named **Samalut Formation** is easily distinguished from the underlying Minia Formation by its creamy colour and by the fact that it carries the first large *Nummulites* of the *gizehensis* type. Following on top of the Samalut and its facies variants, is a 170 m thick limestone section named **Qarara** after the distinctive butte by that name from the plain opposite Maghagha. The Samalut - Qarara succession can easily be traced in the Fayoum Desert and is named **Muweilih Formation** by BEADNELL (1905). In the north Bahariya plateau, the Samalut is replaced by a relatively thin unit known as the Qazzun Formation (32 m thick) of thinly bedded limestones which are chalky in the north and dolomitic in the south.

At Gabal Mokattam east of Cairo, the lower two units of the section, the Lower Building Stone and the *Gizehensis* layers do not seem to have an equivalent at Helwan. The Lower Building Stone interval starts by 2.5 m thick conglomerate which is followed by 25 m thick section of detrital nummulitic limestone. The *Gizehensis* bed is 6-10 m thick. These are followed by two massive limestone units: the Upper Building Stone and the Giushi. The Lower Building Stone and the *Gizehensis* bed can be classified as the proper *gizehensis*-bearing Mokattam beds. The Mokattam Subgroup assumes two facies in the Gulf of Suez: an open bay shale-marl facies (known as the **Darat Formation**) and a reefal nummulitic facies which belongs mostly to the Samalut Formation.

The Observatory Subgroup

The Observatory comprises marine limestone beds in the Cairo area. Many of the formations of this subgroup carry distinctive fossil assemblages and can, therefore, be traced for long distances. The top beds of the subgroup carry characteristic *Gisortia-Dendracis* fauna of Late Middle Eocene age. The type section of this subgroup is the Observatory Plateau at Helwan and is subdivided into the Gabal Hof and Observatory formations. **The Gabal Hof Formation** (121 m thick) is made up of a 100 m thick nonfossiliferous limestone becoming nummulitic toward the top, followed by a 21 m thick extensively burrowed limestone with *Nummulites gizehensis*. The **Observatory Formation** is made up of 136 m of chalky limestones of varying lithologies and textures. The lower 66 m of the section are correlated with the Upper Building Stone interval of the Cairo section (STROUGO 1986) and the upper 70 m are correlated with the Giushi Formation (Fig. 16); both are rich in bryozoa and serpulid remains. The Observatory Subgroup is represented in the east Cairo area (Gabal Mokattam) by the Upper Building Stone member (a wall nearly 70 m high) and the Giushi Formation (thin bedded bioturbated carbonates with serpulid and bryozoan remains).

To the south of Cairo, along the Nile Valley, the Observatory Subgroup becomes difficult to follow as the valley opens up in the Maghagha-Beni Suef stretch, where as a result of the relatively easy weathering of the rocks, the valley becomes exceptionally wide. To the southwest of Fayoum, in the north Bahariya Plateau, the Observatory Subgroup becomes exceptionally thin and is represented by the Middle Eocene beds of Gabal Hamra, the Gabal Hamra Formation. In the Cairo-Suez district and in Gabal Ataqa, the Observatory beds seem to build up

the major part of the scarps. In the eastern side of the Gulf of Suez, Eocene sediments correlatable with the Observatory Subgroup are of limited distribution, represented by the bathyal deposits of the **Khaboba Formation** (93 m thick chalky limestone and gypsiferous shales).

The Maadi Group

The rocks of this group are of more clastic nature than the underlying Mokattam rocks. They are made up mostly of shales with intercalated limestones. The shales are greyish green, highly calcareous and fossiliferous. The limestones are light-dark brown highly argillaceous and locally limonitic. The sediments were deposited in a relatively shallow sea (SAID 1990). The Maadi Group thickens to the south of Cairo and is subdivided in the Helwan area into three formations: the **Qurn**, **Wadi Garawi** and **Wadi Hof** (FARAG & ISMAIL 1959). According to STROUGO & BOUKHARY (1987), the lower two units, the Qurn and Wadi Garawi are of Late Middle Eocene age. The Late Eocene is restricted to the upper beds of the Maadi Group which carry the index fossil *Carolia placunoides* and the Late Eocene Nummulites, *N. fabianii* and *N. incrassatus*.

In the Helwan area, **The Qurn** follows on top of the Observatory Formation. It is made up of 97 m thick sequence of marl and chalky limestones alternating with shales, sandy marls and shell banks rich in *Nummulites beaumonti*, etc... **The Garawi Formation** is a 25 m thick poorly fossiliferous sandy shale sequence with a highly fossiliferous middle bed carrying *Plicatula polymorpha* and *Nicaisolopha clotbeyi*. In many places, this bed becomes phosphatic. In the Fayoum desert, the unit is named **Gehannam Formation** (Ravine beds). It ia a 50-70 m thick sequence of marls and sandstones with occasional bands of limestones.

On the eastern side of the Gulf of Suez, the **Tanka Formation** (68 m thick), may be correlatable with the Qurn and Wadi Garawi Formations.

The deltaic and interdeltaic sediments of the Upper Eocene are exposed to the north of Birket Qarun, Fayoum (Fig. 17), where they form the **Qasr El-Sagha Formation** (180 m thick). Its lower facies is made up of bioturbated (mainly by the crustacean *Callianassa*) glauconitic and fossiliferous calcareous sandstones, carrying shelly marine invertebrates and abraded bones and teeth of transitional marine vertebrates and carbonized wood fragments. From this lower facies came the well-preserved *Prozeuglodon isis* (MOUSTAFA 1974). Interfingering with the above facies is the interbedded claystone and sandstone facies which forms the bulk of the cliffs behind the Qasr El-Sagha temple. From this facies came a rich fauna of fossil mammals, reptiles and fish of marine, transitional marine and terrestrial habitat. It forms the *Moeritherium-Pterosphenus* Zone. The Upper Eocene outcrops are easily distinguished lithologically from the underlying massive limestones of the Middle Eocene and the overlying sandstones and quartzite of the continental Oligocene.

The Economic aspects of the Eocene deposits in Egypt include:

- The production of Bahariya Iron Ore from the Naqb Formation.
- The soft chalky limestones are quarried and mixed with clay in the manufacture of cement at Tura, Qattamiya, Suez, etc. They are also used in the steel industry at Helwan.
- Limestones are quarried from the Mokattam Plateau and are used as building stones. The Pharaonic tombs in the Valley of Kings and the Valley of Queens west of Luxor were excavated in the Lower Eocene

Thebes Formation and the Pyramids of Giza were built from the Middle Eocene Nummulitic "gizehensis" limestones

- Middle Eocene hard crystalline limestones are quarried as marbles and alabaster used for ornamental purposes, e.g. in Wadi Sannour.

The Oligocene

Oligocene deposits overlie Upper Eocene rocks disconformably. According to SAID (1990), they assume two distinct facies: a fluviatile facies of sands and gravels, and an open marine facies of shales and minor limestone interbeds known mostly from the subsurface. This latter facies is similar to that of the underlying Upper Eocene deposits in the north Western Desert and the north Delta embayment. For this reason, the Upper Eocene and Oligocene deposits are usually lumped under the name Dabaa Formation. Oligocene fluviatile sediments crop out essentially along a narrow belt extending from Suez to Fayoum via Cairo and onward into the Westren Desert. These deposits are difficult to date and they are classified with the Oligocene on stratigraphic evidence only. To this facies probably belong the lacustrine to paracontinental deposits of the Red Sea Coast and the Gulf of Suez.

Oligocene marine deposits:

These are recorded essentially from the subsurface of the north Western Desert and the north Delta embayment. This is a shale-marl fossiliferous succession overlying disconformably the Upper Eocene. The most complete marine Oligocene section is recorded from the Dabaa well no.1. It covers the upper part of the **Dabaa Formation** (213 m thick) and the lower part of the overlying **Mamura Formation** (275 m thick). The lower 33 m of the Dabaa Formation are of Late Eocene age (SHEIKH & FARIS 1985). Marine Oligocene deposits were recorded from some wells in the

north Delta embayment e.g. Sneh, Qallin, Monaga, Damanhour south, Kafr El-Dawar, etc... The most complete Oligocene section is found in the Monaga well no. 1 where all the planktonic foraminiferal zones are represented.

Oligocene exposures in the Western Desert:

The most famous Oligocene outcrop in Egypt is the clastic section to the north of the Lake or Birket Qarun. The section is composed of variegated sands and sandstones with alternating beds of shales and marls overlie disconformably the Qasr El-Sagha Formation and underlie unconformably the Widan El-Faras Basalt of Oligocene age. This succession was termed the **Gabal Qatrani beds or Formation** (BEADNELL 1905). Certain beds contain silicified fossil wood together with remains of numerous land animals. Fossils described from the Qatrani Formation include *Arsinoitherium zitteli, Moeritherium* sp., *Paleomastodon* sp. and a large number of tortoises, turtles and crocodiles as well as fragmentary fish remains. The type locality of this formation is at Gabal Qatrani where the maximum development is evident at the conical pictures of hills known as Widan El Faras. Here the thickness of the formation is some 340 m but becomes thinner to the east and gradually vanishing toward the west. At Gabal Radwan in Bahariya Oasis, a 45 m thick unit of nonfossiliferous ferruginous grits, sandstones and quartzites was recorded overlying unconformably the Bahariya Formation. The unit is termed **Radwan Formation** (EL-AKKAD & ISSAWI 1963) and is of Oligocene age.

Oligocene outcrops in the Eastern Desert and Sinai:

Along the Cairo-Suez road unfossiliferous brown sands and gravels are known between the Upper Eocene and the marine Miocene beds, varying in thickness between 40 and 100 m. Scattered through the Oligocene

clastics are huge and massive tree trunks which become concentrated in certain areas where they are commonly referred to as petrified forests (Gabal El-Khashab). The most famous of these is the one that occurs to the east of Maadi, Cairo (Protected area) which attracted the attention of naturalists and scientists. The alignment of the tree trunks and the absence of fruits or any other soft parts attest to the long journey they were exposed to before their silicification.

An interesting Oligocene locality is that of **Gabal Ahmar**, near Cairo, where the richly coloured and variegated sands are traversed by silicified tubes. SHUKRI (1954) gave field evidence that the tubes were formed by uprising fluids carrying iron, manganese and sulphur oxides in the form of fumaroles at the beginning and later in the form of hot mineral springs that did not disturb the sedimentary structures in the sands. The Gabal Ahmar has disappeared under the foundation of Nasr City, NE Cairo since it was last described; it has been renamed Gabal Akhdar, famous for a stadium and a hospital.

In the Quseir-Safaga area near the Red Sea Coast, a 120 m thick unit of coarse breccia beds alternating with fine calcareous clays of bright variegated colours was recognised at Wadi Nakheil. The unit overlies Lower Eocene Thebes Formation and termed **Nakheil Formation** (EL-AKKAD & DARDIR 1966). Equivalent red beds exposed south of Marsa Alam are termed **Abu Ghusun Formation**.

On the eastern side of the Gulf of Suez near Abu Zeneima, the Oligocene is represented by the so called **Tayiba Redbeds**, which forms a succession of variegated (dominantly red) shales and marls which overlies unconformably the Middle-Upper Eocene Tanka Formation and underlies basalt flows or basal Miocene beds. The unit has been so far recorded

from the Sinai coast in the Abu Zeneima-Wadi Feiran area where it assumes at its type section in Wadi Tayiba about 20 m in thickness. The unit carries no fossils and some authors regard it as Late Eocene to Early Oligocene. It is also referred to as the the Abu Zeneima Formation in some works.

Oligocene volcanic activity:

Toward the close of the Oligocene and after the deposition of the Fayoum deltaic and fluvio-marine deposits, Egypt and the whole north Africa were in a state of tension. Under the influence of this tension, fissures were opened and allowed the flow of sheets of basalt. BEADNELL (1905) described many sections in which the basalt appears as a sheet of constant horizon, 25 m in thickness. Basalt flows are known extensively in many parts of northern Egypt and in the Cairo-Suez district (e.g. the quarried Abu Zaabal basalts), along the Cairo-Fayoum desert road and extending continuously to the north of Birket Qarun to reappear in Bahnasa, Bahariya Oasis and to the north of the pyramids of Giza at Tel El Zalat. They were recorded from the subsurface in Khatatba, Mit Ghamr and Wadi El Natrun wells.

Palaeogeography of the Paleogene

The Paleogene transgression pushed its way across the southern borders of Egypt into north Sudan (SAID 1990). The maximum transgression occurred during the Late Paleocene. After the Paleocene and all through the Cenozoic, the sea kept retreating toward the north almost continuously except for short intervals. The sediments that this sea left behind were affected to a large extent by the relief which was inherited from the Late Cretaceous tectonics and the movements which continued episodically during most of the Paleogene. The result was that while the Paleogene

outcrops of the Unstable Shelf are thin and disconnected, those of the Stable Shelf are thick and in the form of extensive tablelands. This marks the clearest distinction between the Stable and Unstable Shelves.

A large part of the Stable Shelf was overlapped by the sea during the Paleocene when the maximum transgression took place. The Gabal Abyad facies of northern Sudan is similar to the Arbain facies of the Paleocene Kurkur Limestone of south Egypt and it is possible that both were formed in one basin. During the Early Eocene, the shoreline receded to south Egypt where relatively thin and uniform sediments covered this great embayment. The earliest Eocene is represented by the upper beds of the Esna Shale and the Farafra Limestone. The main facies of the carbonate rocks, the Thebes, indicates deposition in a continuously shallowing sea.

The retreat of the sea toward the north uncovered large parts of the Stable Shelf and brought the shoreline of the Middle Eocene to the latitude of Minia. The facies of the Middle Eocene rocks along the southern border of this basin is unique attesting to the intense tectonics to which many parts of Egypt were subjected. With the advent of the Late Eocene, the Stable Shelf was almost completely uncovered with the exception of the Fayoum-Gindali Basin where shallow marine sediments accumulated (SAID 1990). Toward the southwest of the basin, a great river must have debouched into the sea forming the Qasr El-Sagha delta (Fig.17). During the Oligocene, remains of fluvial sediments littered the Stable Shelf area. The northern outcrops of the Gabal Ahmar and Gabal Qatrani Formations cover the southern borders of the Cairo-Suez-Kattaniya high in almost continuous outcrop.

In the Unstable Shelf area of north Western Desert, the Paleogene rocks are divided into two major units: a lower marl-limestone unit of

Paleocene-Middle Eocene age, the **Apollonia** and an upper marl-shale unit of Late Eocene-Oligocene age named the Dabaa Formation. In the north Sinai, the Eocene plateau limestones are divided into a lower unit of Lower Eocene limestone with chert (the Thebes) and an upper unit of Middle Eocene chalky limestone (the Mokattam Formation). The Thebes Formation is similar in lithological characters to the Thebes Formation of the Stable Shelf but is much thinner. Also, the extensively developed Mokattam Formation of Sinai is thin. It does not exceed 100 m in thickness except in a few places. The Late Eocene saw the withdrawal of the sea to the north and the elevation of Sinai and the western part of the north Western Desert which formed an embayment. The Late Eocene embayment in north Egypt continued during the Oligocene except for a minor retreat (SAID 1990).

Cretaceous/Paleogene stratigraphy of selected areas in Egypt

In the following pages we threw more light on the distribution of the Upper Cretaceous/Eocene rock units in some selected localities of the Stable Shelf areas where these rocks are best developed and sufficiently studied.

i) Stratigraphy of the Farafra Oasis:

Three extensive mappable rock units make the floor and slopes around this oasis. These units are from top to bottom:

- Farafra Limestone, 24 m, Early Eocene
- Esna Shale, 120-160 m, Thanetian at its middle the Maqfi Limestone
- Khoman Chalk, 24 m, Maastrichtian

The depression is cut in a white chalk, forming the **White Desert** protected area, of Maastrichtian age. Fossils are *Pecten farafrensis, Ventriculites poculum, Schizorhabdus libycus* and *Globotruncana-*

Heterohelix foraminiferal assemblage (SAID & KERDANY 1961). Overlying the chalk is a series of slope-forming green shales that belong to the Esna Shale rock unit. These shales pass with an increase of calcareous material and corresponding loss of clastics into the Farafra Limestone above.

Structurally, the Farafra Oasis represents a minor dome. Beds on both the eastern and western scarps dip very gently to the east and west respectively. There is a regional dip to the north. The presence of an unconformity between the Maastrichtian and the Late Paleocene (Thanetian) shows that uplifting occurred in Early Paleocene time, a movement that seems to have continued mildly at intervals during the Late Paleocene.

ii) Stratigraphy of the Dakhla Oasis:

Five rock units are exposed; from top to bottom:

-Tarawan Chalk, 38 m, Danian;

Includes a fauna of reefal forms as *Ventriculites poculum, Schizorhabdus libycus, Echinocorys fakhryi* and a *Globorotalia* foraminiferal assemblage.

-Dakhla Shale, 228.5 m, Maastrichtian-Danian;

Includes *Cardita wagneri, Lucina dachlensis, Exogyra overwegi, Crassatella zitteli, Roudairea drui,* etc. The type section of the formation lies north of Mut.

-Duwi or Phosphate Formation, 21 m, Campanian-Maastrichtian;

The actual phosphates are in the form of several distinct bands, separated by intervening shale beds. Average thickness of the phosphate beds ranges from 2-3 m, usually dark brown and appears to be made largely of coprolites and broken vertebrate fragments.

-Qusier Variegated Shale or Mut Formation, 71.5 m, Coniacian-Santonian.

-Nubian Sandstone, 222 m.

The former Nubia Sandstone is recently replaced by the following units from top to bottom (KLITZSCH & HERMINA 1989):

. Taref Sandstone (Turonian)

. Maghrabi Formation (Cenomanian)

. Sabaya Formation (Albian-Cenomanian)

. Abu Ballas Formation (Aptian) and

. Six Hills Formation (Barremian-Neocomian)

The Dakhla area can be structurally considered as a major broad syncline located on the northern plunge of the Nubia huge up warping which exists far to the south. It possibly forms an integral part of a more regional syncline enclosed between Kharga swell to the east and Bahariya-Farafra swell to the northwest. A series of alternating anticlinal and synclinal warping of varying intensity are present within the major syncline. Faults of variable trends and magnitudes do occur in the Dakhla area. Formation of the Dakhla depression came into action by erosion during the Oligo-Miocene times.

iii) Stratigraphy of the Kharga Oasis:

AWAD & GHOBRIAL (1967) summed up the geologic colum at the Kharga Oasis as follows, excluding the diluvial, playa, caliche, travertine and aeolian deposits of the Quaternary:

-Thebes Formation: 76 m thick, limestone with chert bands, fossiliferous with *Nummulites deserti, Operculina libyca,* etc... (Ypresian).

-Esna Shale: 107 m thick, grey green shale layers with no macrofauna, but *Globorotalia* Assemblage. (Thanetian).

-Tarawan Chalk: 50 m thick, changing laterally to Kurkur Limestone with *Ostrea orientalis*, etc (Type section, G.Tarawan, Kharga). (Danian).

-Dakhla Shale: Three members

. Kharga Shale Member, 55 m thick, Maastrichtain-Danian,

. Beris Oyster Mudstone Member (15 m thick), Middle Maastrichtian,

. Mawhoob Shale Member (30 m thick), Early-Middle Maastrichtian.

-Duwi (Phosphate) Formation: 7 m thick, alternating layers of phosphates, phosphatic limestone and shale, Campanian-Maastrichtian.

-Qusier Variegated Shale: 60 m thick (named Mut Formation by KLITZSCH & HERMINA 1989)

-Taref Sandstone: 80 m thick (type locality is Gabal Taref, Kharga)

-Abu Bayan Sandstone and Shale: 585 m thick. This unit is subdivided by KLITZSCH & HERMINA (1989) into:

. Maghrabi Formation (Cenomanian),

. Sabaya Formation (Albian-Cenomanian),

. Abu Ballas Formation (Aptian) and the

. Six Hills Formation (Barremian-Neocomian).

-Abu Bayan Granite: Precambrian weathered basement.

The geological structure of the Kharga Oasis is simple. The strata are almost horizontal with dips varying between 1° and 2° to the west-southwest and to the east-southeast. The depression, therefore, forms a gentle fold that trends almost in a north-south direction. The most striking tectonic feature in the entire Dakhla-Kharga stretch is the presence of a large north-south fault bounds the eastern scarp of the Kharga Oasis. This fault, first noted by BALL (1900) and delimited by BEADNELL (1909), runs in the centre of the Kharga depression for almost 100 km. That fault is of normal type.

iv) Stratigraphy of the Nile Valley between Aswan and Qena:

This is best represented by Gabal Awaina section, opposite Esna which is the type locality of the Esna Shale. The stratigraphic succession at this locality is as follows from top to bottom (Fig. 18).

-Thebes Formation: 20 m thick, Ypresian age. Hard limestone with chert concretions.

-Esna Shale: 104 m thick, Thanetian age. Laminated grey and green shales with foraminifers

-Tarawan Chalk: 22 m thick, Danian age, changes laterally into Kurkur Limestone.

-Dakhla Shale: 185 m thick, Maastrichtian-Danian.

-Phosphate or Duwi Formation: about 4 m, Campanian-Maastrichtian.

- Qusier Variegated Shales: Coniacian-Campanian, base not exposed.

The Paleocene/Eocene GSSP boundary has recently (Feb. 2004) been defined within the upper part of the Esna Shale in a pharaonic quarry at Dababiya, 35 km south of Luxor. The paleontologic boundary coincides with evidence of the Late Paleogene isotopic excursion.

v) Stratigraphy of Wadi Qena area:

Wadi Qena has its deltaic mouth at the town of Qena; its course extends in a north-south direction. From the southern end of Gabal Abu Had at the mouth of Wadi Qena, BARRON & HUME (1902) described the following succession from top to bottom (composite section); the Quaternary sediments are excluded and the corresponding name of the rock stratigraphy is indicated:

-Serai Limestone = Thebes Formation	265m
-Grey laminated shales = the Esna Shale	60m
-Yellow Limestone = Tarawan Chalk	6m
-Dakhla Shale: Greyish green shales and yellow marl with *Pecten farafrensis*................................	60m
-Duwi Formation:..	4.2m
-Qusier Variegated Shales which pass below into carbonaceous shales..............................	+15m

The carbonaceous shales are underlain by a series of sandstone beds occupying the country between Gabal Abu Had and the basement complex to the east. Passing to the north, Wadi Qena is cut in sandstone beds directly overlying the peneplained surface of the basement. Above which, to the west, Cenomanian deposits are noted. Overlying this is another unit yielding Turonian and Santonian fossils.

vi) Quseir-Safaga District:

The startigraphy of the exposed sedimentary rocks in the Qusier-Safaga area is described under the following rock units excluding the Oligocene to Recent:

- Thebes Formation (140 m thick),
- Esna Shale (80-220m thick)
- Tarawan Chalk/Kurkur Limestone (80 m thick)
- Dakhla Shale (165 m thick), the lower layers are marl,
- Duwi (Phosphate) Formation (66 m thick), type locality of the formation is Gabal Duwi.
- Quseir Variegated Shales (70 m thick, type section is Gabal Atshan), and
- Taref Sandstone.

The Taref Sandstone rests unconformably over the peneplained basement complex. The Qusier Variegated Shales are nonfossiliferous and reach 70 m in thickness at Gabal Atshan. The Duwi Formation is composed of hard siliceous limestone, marl beds and a number of phosphatic lenticular beds. At Atshan area, the Duwi Formation attains a thickness of 66 m (Fig. 19). The top phosphatic bed in this formation, so called Atshan bed was exploited in Atshan and Nakheil mines. The thickness varies from 160-170 cm and the T.C.P. content is between 65-70%. The middle phosphatic bed was exploited at Duwi mine (150 cm, 70% T.C.P.). The lower bed (3m thick and 60-40% T.C.P.) is being exploited at Hamadat mine.

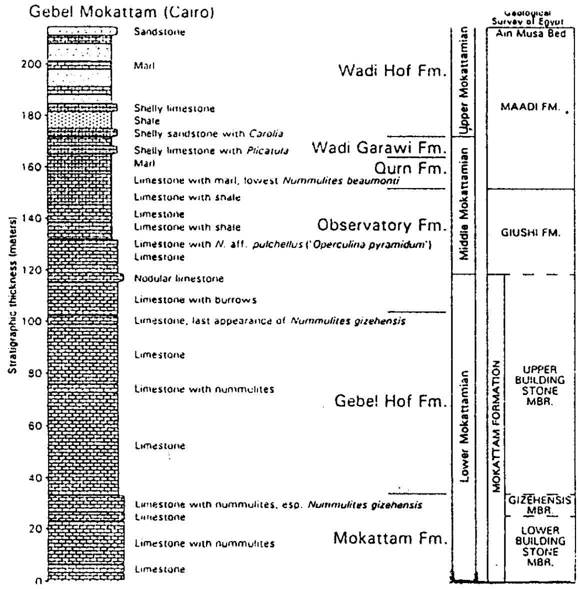


Fig. (16): Interprertation of the Eocene stratigraphic succession at Gabal Mokattam (after STROUGO 1986 & SAID 1990)

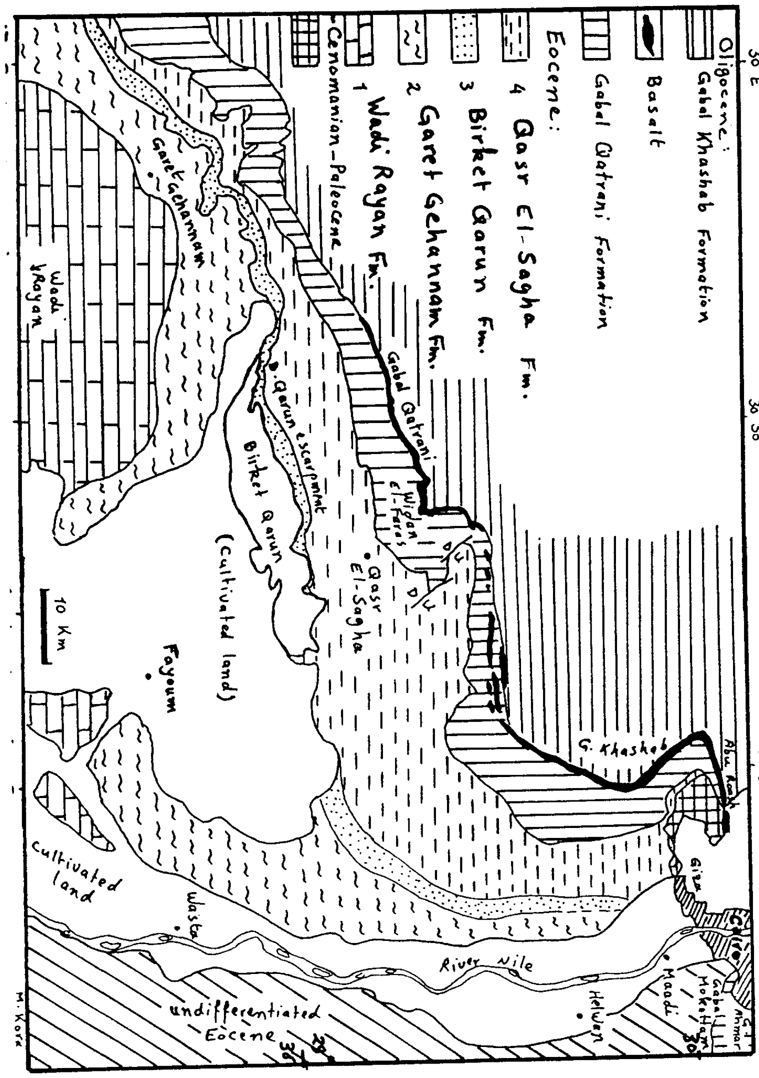


Fig. (17): Geological map of the Fayoum Province, simplified after the Geological Survey of Egypt.

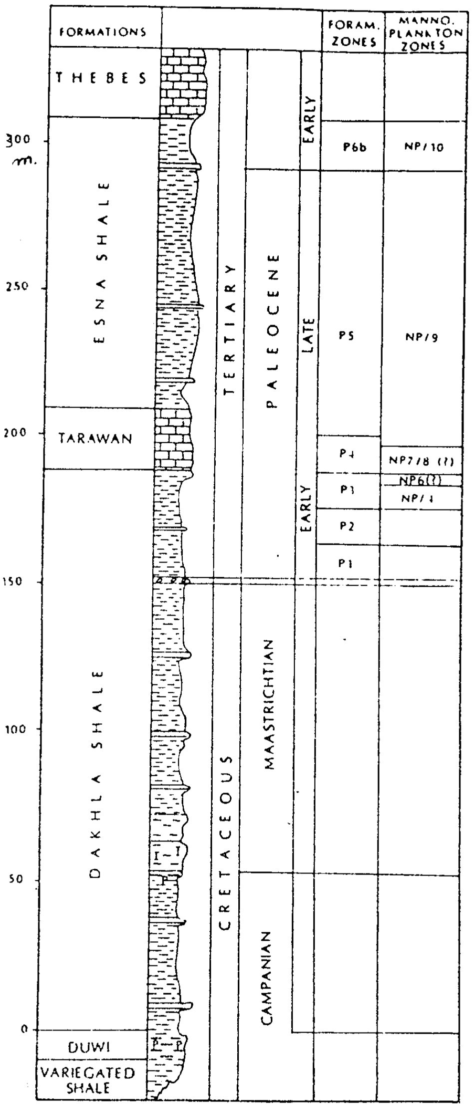


Fig. (18): The Cretaceous-Tertiary stratigraphic succession in Gabal Awaina section, Esna (from SAID 1990).

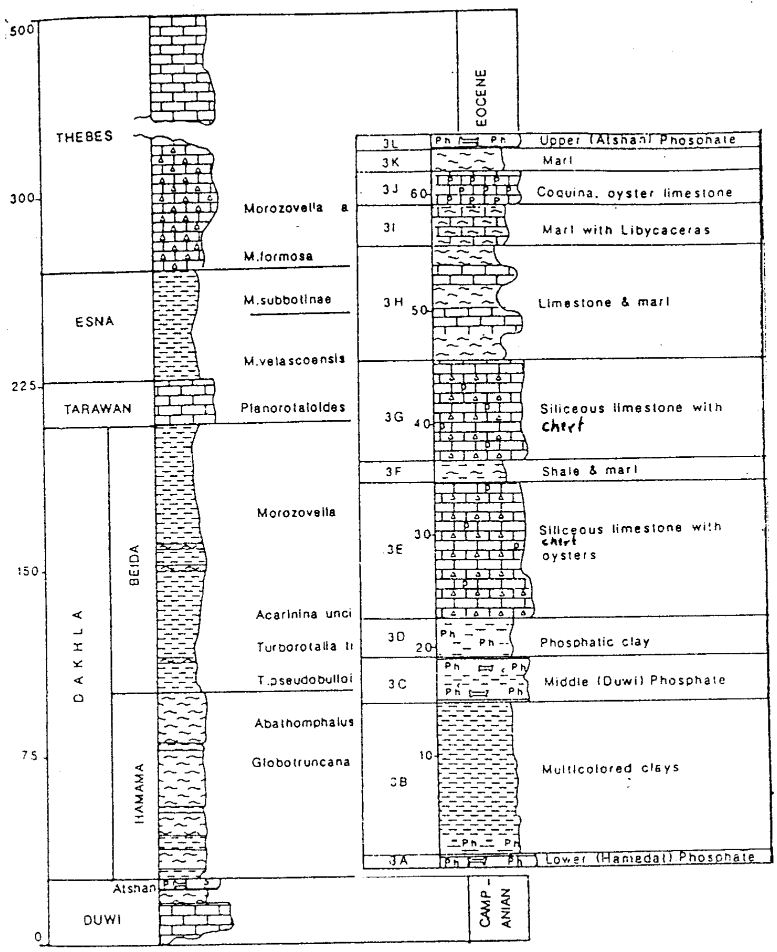


Fig. (19): Columnar section of Gabal Duwi and the type section of Duwi Formation (after YOUSSEF 1957).

The Neogene

The advent of the Neogene subperoid was marked by intense tectonic movements which had a great effect on the present day structural framework of Egypt. Early Miocene rifting produced the Gulf of Suez and the Red Sea grabens in more or less their present shape. The Miocene was terminated by a spectacular event which caused the desiccation of the Mediterranean basin, the lowering of the base level and the beginning of an immense erosional period which shaped the modern face of Egypt (SAID 1990). The geochronology of the Neogene is based, to a large extent, on palaeontological and stratigraphical evidence. Successful taxa used in dating the Neogene rocks of Egypt are the planktonic foraminifers and calcareous nannoplanktons.

The Miocene

The Miocene sediments exhibit great facies variations and have a large number of unconformities reflecting the nature of tectonically formed basins in which they were deposited. The maximum marine transgression of the Miocene Epoch occurred during the Burdigalian when the sea covered large areas of north Egypt and overflowed into the newly formed Gulf of Suez. A large part of the transgressing sea was under the influence of fluvial sedimentation forming a wave-dominated delta plain covering the eastern part of the north Western Desert.

Four distinct tectonic provinces can be distinguished in the Miocene: the Gulf of Suez and Red Sea elongated basins, the Cairo-Suez neritic marginal zone, the north Delta embayment with a thick Neogene section, and the north Western Desert basin. In each of these provinces, the Miocene assumes peculiar facies characteristics and in each, the

stratigraphic section is divided into units which are difficult to correlate with those of the other districts.

i) The Miocene in the Gulf of Suez and the Red Sea Coast:

The Miocene sequence of the Gulf of Suez is commonly subdivided into a lower unit, referred to as the Gharandal Group and an upper unit referred to as Ras Malaab or Evaporites Group, as follows from top to base:

-Ras Malaab Group (Middle to Late Miocene):
-Zeit Formation
-South Gharib Formation
- Belayim Formation

-Gharandal Group (Early to Middle Miocene):
-Kareem Formation
-Rudeis Formation
-Nukhul Formation

Both groups are important, the lower containing the richest source rocks in combination with excellent reservoirs deposited under most favourable structural conditions, and the upper group providing the most efficient seal for both Miocene and the Pre-Miocene reservoirs. The thickness of these two groups is about twice that of the Pre-Miocene formations. It indicates a fast subsidence of the graben area within a short period of time and a predominantly restricted depositional environment.

Nukhul Formation (100 m average thickness) contains carbonates and high energy reefal buildups on pre-Miocene topographic highs, and sands and shales in the lows between fault blocks. **Rudeis Formation** overlies the Nukhul and is composed essentially of highly fossiliferous shales and marls referred to as the *Globigerina* Marl, and sandstones. The Rudeis is thick; thickness of 2000 m is common. This

formation is oil bearing in Balayim, Morgan and other fields. **Kareem Formation** (260 m at type section) is predominantly shale but with frequent intervals of sandstones. Shales of the Rudeis and of the Kareem formations are considered by some authors to be the main source rocks of the Gulf area. The interbedded sands provide excellent reservoirs with porosities ranging from 11 to 24%. The average thickness of the Gharandal Group is about 1400 m.

Belayim Formation (302 m thick at the type section) is composed of rock salt, with evaporites at the bottom and clastic section at the top. The sandstone interbeds serve as good reservoirs in several fields. On the high pre-Miocene structures where the Lower Miocene was not deposited, Balayim Formation represents the first Miocene sediments and consists of reefal limestone with excellent reservoir characteristics. **South Gharib Formation** (701 m thick at type section) is the most persistent evaporite section, composed mainly of anhydrite and rock salt with minor thin shale beds. **Zeit Formation** (941 m thick at type section) consists of alternations of shales and anhydrites. These Miocene evaporites are believed to have originated on coastal sabkhas (supratidal flats) where no biological organisms could survive the super saline environment, and the Late Miocene age is determined on stratigraphic grounds. Ras Malaab Group attains a cumulative thickness of about 3200 m.

Along the Red Sea, the Miocene occupies a strip on the coast to the south of Hurghada. It is also a basin deposit which transgressed older rocks on all sides of the sea and is represented also by marine to paralic deposits. The Miocene in this stretch is much thinner and is composed of a marine carbonate unit at base, followed by a thick evaporite sequence in the middle and is topped by a thin clastic unit (Fig. 20). EL AKKAD &

DARDIR (1966) named them the **Gabal Rusas** Formation (30-60m thick), the **Abu Dabbab** Gypsum (50m thick), and the **Samh** Formation (10-40m thick), respectively. The upper boundary of the Miocene in the Red Sea coastal area is drawn on the top of this latter formation and the first appearance of Indo-Pacific forms which mark the overlying oyster and cast beds of the Pliocene (Gabir Formation). The lower boundary of the Miocene in that area is either the nonconformable contact with the Precambrian Basement or the Oligocene red bed succession of the Nakheil/Abu Ghusun Formation. South of Marsa Alam, the Gabal El Rusas Formation could be subdivided into a lower clastic unit, the **Ranga** and an upper reefal unit known locally as **Um Mahara** Formation.

ii) The Miocene of the Cairo-Suez district:

Here, the Miocene section is relatively thin and increases in thickness from west to east; it is 30 m thick in the area to the east of Cairo, 80 m thick in Gabal Oweibid, 118 m thick in Gabal Genefa, and 180 m thick in Abu Sultan well to the north of Gabal Shabraweet. These rocks include lower marine richly fossiliferous sediments and an upper unit made up of non-marine fluviatile sediments.

Marine Miocene sediments overlie the Oligocene with a minor unconformity and assume a uniform shallow-water neritic facies. The faunal assemblage is composed mainly of oysters and pectens forming embankments and includes gastropods, corals, echinoids and bryozoans. Above the marine Miocene there are about 20 m of grits and gravels, usually cover the outcrops giving them the appearance of dark small hillocks, similar to the Oligocene hillocks.

iii) The Miocene in the north Delta embayment:

A Miocene cycle consists of formations ranging in age from Early to Late Miocene (Fig. 21), including Sidi Salem Formation, Qawasim Formation and, on the top; the Rosetta Formation was described by RIZZINI *et al.* (1978)

- -The **Sidi Salem Formation** (1000 m thick) is composed mainly of clay with few interbeds of dolomitic marls and rare streaks of sandstones, characterized by benthonic forams of Langhian to Tortonian age
- -The overlying **Qawasim Formation** (965 m thick) is a rather irregular succession of fairly thick layers of sands, sandstones and conglomerates containing rare Messinian fauna.
- -The **Rosetta "Anhydrite" Formation** (50 m thick) may be correlated with the evaporites of the Messinian Mediterranean basin due to its stratigraphic position.

iv) The Miocene of the north Western Desert:

In the Western Desert, the Miocene is extensively developed and covers a large tract of the northern part. It is divided into two rock units coinciding to the Lower and Middle Miocene; Moghra Formation and Marmarica Limestone, respectively.

The Moghra Formation consists of a thick (203m) clastic section of variegated shales, thin marls, sands and calcareous grits with large quantities of silicified trees and few scattered fluviomarine fossils. It is particularly developed to the south of a line that runs from Siwa to Wadi El Natrun and forms a conspicuous part of the northern Qattara wall.

The Marmarica Limestone covers the Marmarican Plateau to the north of Siwa - Wadi El Natrun line. It is very uniform in character and

practically horizontal. It is made of a solid limestone (78 m thick) that becomes a little sandy towards the east. It is rich in shallow marine Langhian fossils as *Scutella zitteli, Echinolampus amplus, Ostrea digitalina*, etc...

Economic mineral deposits:

In addition to the importance of the Miocene sediments as being the main Oil-producting horizon in the Gulf of Suez, some of the Miocene mineral deposits are of economic importance: Gypsum is quarried from the Middle and Upper Miocene at Ras Malaab, southwestern Sinai. Also, lead, zinc, manganese and sulphur as metasomatic replacement hydrothermal deposits of some Miocene sediments occur along the Red Sea Coast.

The Pliocene

The advent of the Pliocene Epoch was marked by the flooding of the Mediterranean basin across the Gibraltar Strait and the gradual in-undation of the north Delta embayment, the northern coastal areas and the Eonile canyon by this sea. The Gulf of Suez and the Red Sea, which had been isolated from the Mediterranean, were connected with the Indian Ocean across the Bab El-Mandab Strait. Thus, the Pliocene exposures in Egypt occur mainly in the northern parts of the country but extend also to the southernmost limit as a narrow strip in the Nile Valley or along the Red Sea Coast. They include two main facies; a marine facies and a non-marine facies.

i) The marine Pliocene:

The marine Pliocene includes the rocks which crop out in the Nile Valley region along both banks of the river from Giza up to Aswan, as well as

those cropping out along the Red Sea and the Mediterranean coasts. The Nile outcrops abut against older strata with a depositional dip and assume a marly limestone fossiliferous facies typified by the clastic section at Kom El Shelul (**Kom El Shelul Formation**, 25 m thick) south of the pyramids of Giza which is the most fossiliferous Pliocene outcrop in Egypt (SAID 1971).

The Red Sea Coast occurrences form a strip along that coast (Fig. 20) and include the well known oyster and cast beds (**Gabir Formation**) and the *Clypeaster-Laganum* series (**Shagra Formation**). These lie unconformably over the Miocene rocks of the Red Sea Coast and are separated from the latter by virtue of their possession of an influx of oysters and echinoids of Indian Ocean affinity (Fig. 20). At Zug El Bohar, these include calcareous sandstone and shelly algal biomicrite, indicating deposition in a shallow near land marine environment (El SHAZLY 1977). Around Marsa Alam, the Shagra Formation is overlain unconformably by an older part of the Pleistocene organic reefs and conglomerates usually referred to as the **Samadai Formation** of Plio-Pleistocene age (KORA & ABDEL FATTAH 2000).

The Mediterranean Coast occurrences form a strip made up of a 25 m thick buff to pink dolomitic limestones referred to as the **Hagif Formation** after a type locality to the northwest of Wadi Natrun. In this locality, the formation becomes thicker (80 m) and includes workable gypsum beds. Pliocene outcrops occur in the Nile-Fayoum divide and belong most probably to the marine Pliocene of the Nile gulf. The base of most of these outcrops is not exposed; the beds are mostly sandstone that is fossiliferous in places and contains Pectens and oysters. In the subsurface of the Nile Delta area, thick marine to deltaic Pliocene strata

are recorded and are subdivided into the sandy beds of **Abu Madi Formation** (uppermost Miocene-Lower Pliocene, 250 m thick), the silt shales of **Kafr El-Sheikh Formation** (Lower to Middle Pliocene, 1200 m thick) and the quartzose sands of **El Wastani Formation** (Upper Pliocene, 300 m thick). The shallow marine Abu Madi Formation is the main gas producing horizon of the Nile Delta gas fields (Fig. 21). Recently, the gas is produced also from the sand lenses of the overlying Kafr El Sheikh and even El Wastani formations, particularly in the offshore area.

ii) The non-marine Pliocene:

The non-marine Pliocene is separated into two facies: the first includes Pliocene deposits in or around the Nile Valley and the second contains lacustrine, spring and geyser deposits in areas outside the valley.

The Nile Valley non-marine Pliocene includes the brackish water sands and clays of the *Melanopsis* Stufe which crop out along the eastern banks of the Nile in its northern reaches; and the Wadi Natrun deltaic vertebrate-bearing sands, shales and marls (**Gar El Meluk Formation**, 33 m thick). It includes also the lacustrine deposits of the southern reaches of the valley known in their best occurrence in Wadi Qena. These include the proper lacustrine sediments of the chocolate brown clays, pond sediments and diatomites capped by the zoned travertine of Issawia (**Issawia Formation**).

Outside the Nile Valley, the non-marine Pliocene includes a variety of deposits which could be ascribed to spring activity or to deposition in ephemeral or more permanent fresh water lakes (SAID 1971). The most famous of these are the plateau and slope travertine of Kharga, Dakhla, Kurkur and Dungul Oases which could be of several

generations up to the Quaternary. Included also here are the chalcedony beds and calcite sheets of the south Western Desert studied by ISSAWI (1969) and the porcellaneous limestones of Gabal Hamzi which are 35 m thick and named **Hamzi Formation** (SAID 1971). In the Cairo-Suez district and in the depression between Gabal Ataqa and the Northern Galala, a 20 m thick sequence of calcareous sandstone beds overlies unconformably the marine Middle Miocene. They are named **Hagul** Formation (SAID 1990). The top 2 m thick sandy limestone bed with chert which caps the Hagul, is equivalent to the Hamzi Formation.

The Quaternary

The Quaternary sediments lie unconformably over the Pliocene or older sediments in the Nile Valley and the surrounding deserts. Of these two environments, the Nile trough possesses the more complete record of the Quaternary in Egypt (SAID 1990). Here, the sediments assume great thicknesses and are divisible into units which are unconformable with one another. The correlation of the sediments of the different environments is difficult because of the presence of great gaps in the sedimentary record and because the precise age of most of the sediments is unknown.The Quaternary sediments in Egypt have been subdivided by BALL (1939) into seven types. In the light of the present investigations, these are:

- Raised beaches and coral reefs along the Red Sea Coast, including also the beach sands.
- Oolitic limestone ridges on the Mediterranean Coast.
- Alluvial deposits in the Nile Valley and the Delta.
- Lacustrine deposits and the Nile mud in Fayoum Depression.
- Alluvial and wadi deposits in the drainage channels of the deserts.
- Calcareous tufa, caliches, calcrete and playa deposits in the oases.

- Dunes and other aeolian accumulations on the northern coast and the deserts, e.g. in the Great Sand Sea.

Deep drilling in the present Nile Delta has contributed greatly to our understanding of the Quaternary geology of this area. The Plio-Pleistocene gravelly sands of the **Mit Ghamr Formation** (700 m thick) are dominantly fluviatile in origin and are the main aquifer in the Nile Delta region. They are also quarried for sands and gravels on the Delta flanks. It is equivalent to the Abbassia Gravels and the Qena Sands in the valley terraces. **Baltim Formation** is its marine equivalent in the offshore wells. The Holocene sandy mud of **Bilqas Formation** (50 m in maximum recorded thickness) constitutes the agricultural soil allover the area (Fig. 21).

Pleistocene carbonate sand bars (oolitic limestone ridges) occur along the Mediterranean Coast west of Alexandria (**Alexandria Formation**). There are various opinions regarding the origin of these bars, but recent observations point to the formation of carbonate sands and granules in the Mediterranean Sea near the coast and their transportation inland by the retreat of the sea under general arid warm conditions.

Along the Red Sea Coast, the Pleistocene sediments are mainly of shelly coralline facies deposited under shallow reefal marine environment (Fig. 23). Sabkhas, Salinas and other Quaternary evaporites are widely distributed in the coastal zone. Small sand dunes and wind-blown sands fixed by halophytes are also observed. Some of the beach sediments are black sands; others are cemented to form beach rocks. The wadi deposits and fanglomerates are composed of alternating beds of gravels, sands and mud in fining upward cycles and can be easily quarried. They are an important aquifer along the Red Sea Coast as well as in Sinai.

Fig. (20): **Pliocene macrofauna from the Red Sea coastal plain (after KORA & ABDEL FATTAH 2000)**: 1. *Crassostrea gingensis*, 2. *C. crassissima*, 3. *Lopha* (*L.*) *virleti*, 4. *Tapes* (*C.*) *sallomcensis*, 5. *Cardium suezensis*, 6. *Clypeaster reticulatus*, 7.C. *kamaranense*, 8. *Laganum depressum*.

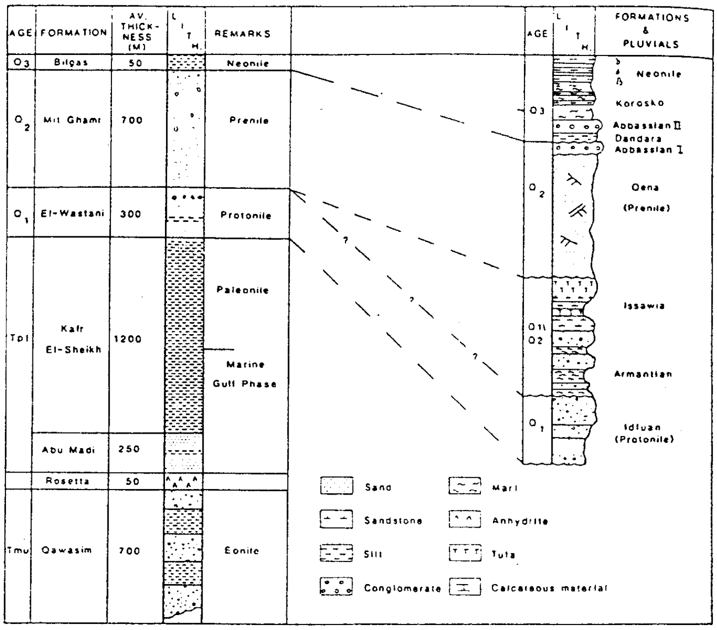
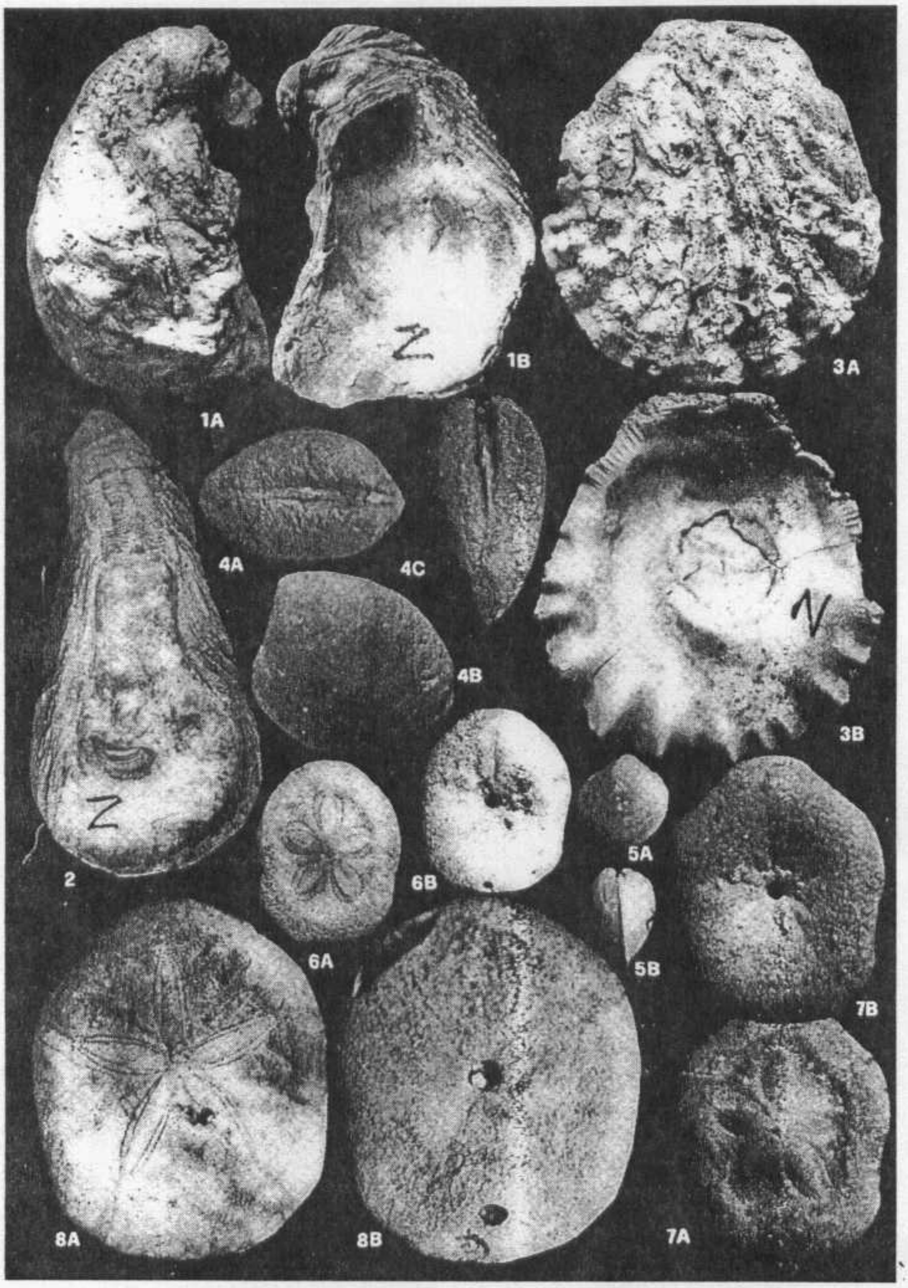


Fig.(21): Tertiary-Quaternary stratigraphic succession in the Nile Delta subsurface, compared with surface sediments of the Nile Valley in Upper Egypt (from SAID 1990). Surface section enlarged 2.5 times in comparison to that of the subsurface.


1A
1B
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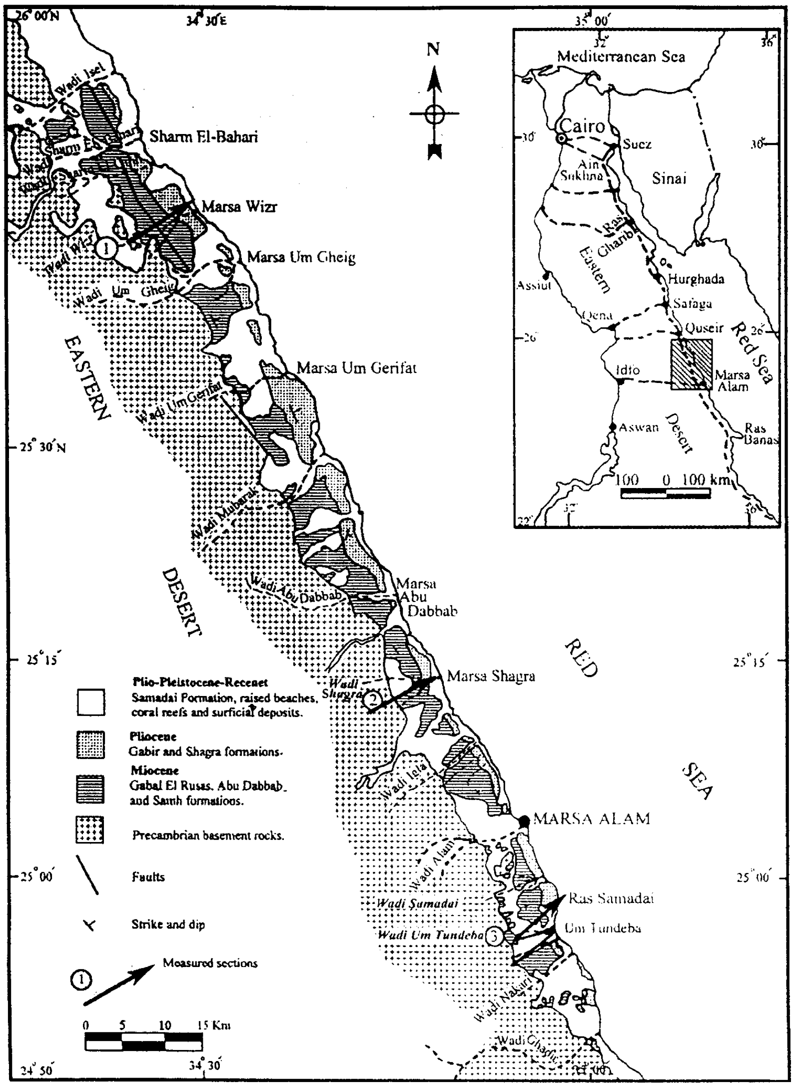

Fig. (22): Geological map of a part of the Red Sea coastal plain modified after the Geological Survey of Egypt by KORA & ABDEL FATTAH. (2000).

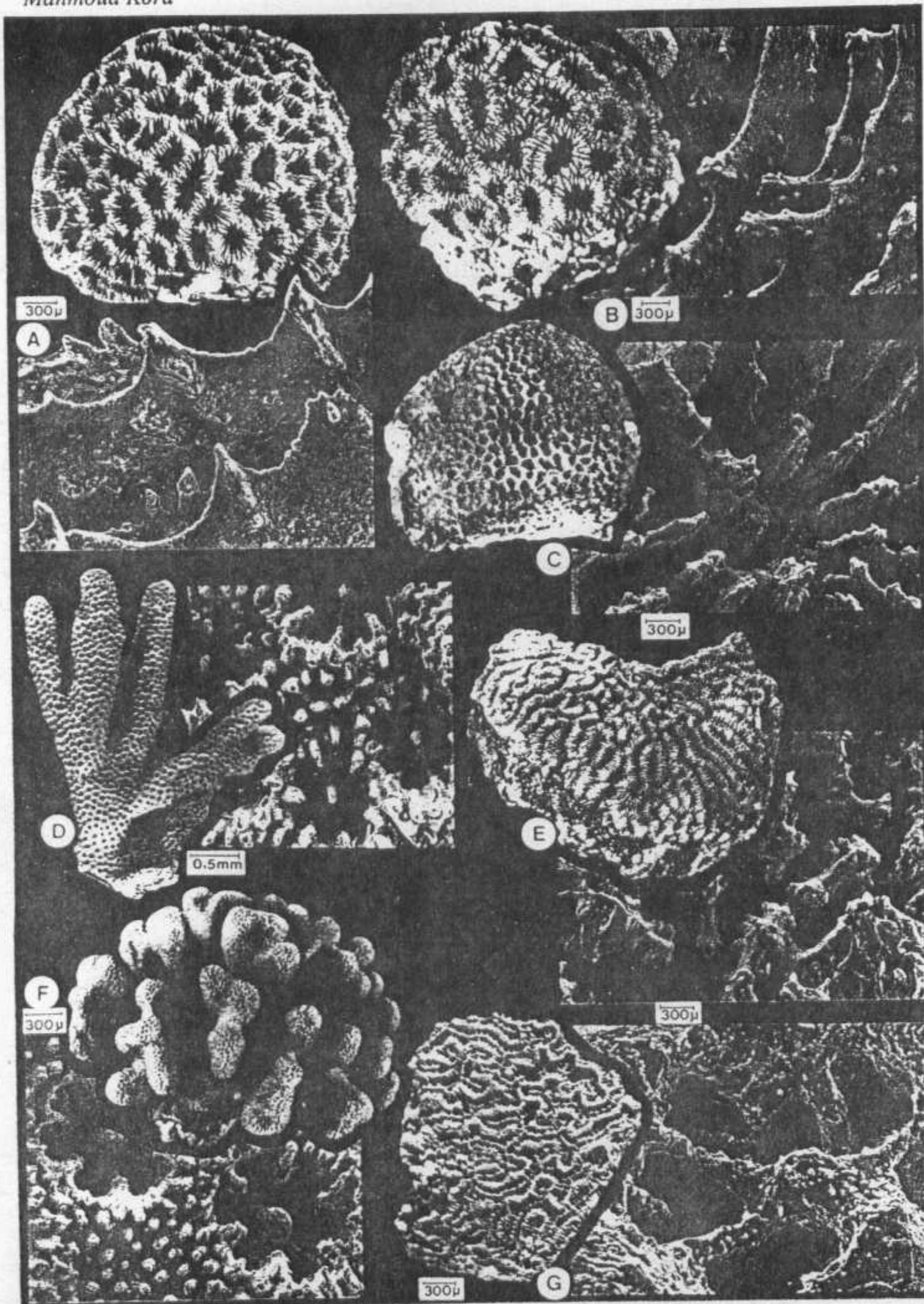

Fig. (23): Corals from the Quaternary raised beaches of the Red Sea Coast; A-C: *Goniastrea*, D&F: *Stylophora*, E: *Platygyra*, G: *Leptoria* (From JUX 1984).

The geological evolution of the River Nile in Egypt

Under this title SAID (1981 & 1990) has summed up what is known at present about the development of the Nile system in Egypt. Sediments form one of the chief sources of information; they show great changes in the river valley since its "down cutting" through earlier rocks in the Late Miocene. Five river phases succeeded each other: the Eonile in the Late Miocene, Paleonile in Late Pliocene, and the Proto-, Pre- and NeoNile in the Pleistocene. These phases were separated by "episodes", with the river declining or even ceasing its flow for reasons of tectonic and climatic changes.

Age	River Phase	Rock unit (Formation)
Holocene	δ Neonile	Arkin-Bilqas
Late Pleistocene	γ/δ recession	Dishna-Ineiba
	γ Neonile	Sahaba-Darau
	5.Neonile β/γ recession	Deir El Fakhuri
	β Neonile	Masmas-Ballana
	α/β recession	Koroska-Makhadma,
		Abbassia II
Middle Pleistocene	α Neonile	Dandara silts
	Prenile/Neonile	Abbassia I
	4. Prenile	Qena-Mit Ghamr
Early Pleistocene	3.Protonile	Idfu - El-Wastani
	Paleonile/Protonile	Issawia/Armant
Late Pliocene	2. Paleonile	Madamud/Kafr El Sheikh
Early Pliocene	Eonile/Paleonile	Kom El Shelul
Late Miocene	1. Eonile	Rosetta
		Qawasim

The northern part of the Delta was a sea bay (north Delta embayment of SAID 1981) of the Mediterranean surrounded by mountains west and

south; a south Delta block was caused by faulting in Late Eocene and Pre-Miocene.

Late Miocene:

There was a regression of the sea and a drying up of the northern Delta. The Mediterranean shrank into a series of salt lakes and finally dried up completely about 5.5 mill. years ago (HSÜ *et al.* 1973). With a low sea bed level, erosion was intense and the ancient Nile Valley began to form, with the Egyptian Eonile cutting a deep gorge 183 m below the present sea level at Aswan and 509 m at Cairo region and still deeper in the Delta. The course of this river was determined by faulting with shifts, from a northwestern course to the Qattara Depression, to a more northerly course. The sediments of the Late Miocene Eonile are in the form of coarse clastics (Qawasim Formation) known in the subsurface of the north Delta embayment, followed by the Rosetta Evaporites.

Qawasim Formation

Type section: Qawasim well-1; 2800 - 3765 m interval.

Lithology: Thick layers of sands, sandstones and conglomerates interbedded with thin clay layers.

Limits: Overlies Sidi Salem and underlies Rosetta Formation.

Extent: North Delta embayment in the subsurface.

Fossils: Late Miocene rare ostracods and foraminifers

Early Pliocene:

The sea was reconstituted by Atlantic inflows at Gibralter and advanced along the Eonile Valley as far as Aswan, drowning the valley. Sediments of this Lower Pliocene contain planktonic foraminifera in the north and brackish water organisms in the south. These include the sands of Abu

Madi Formation and the shales of the lower part of Kafr El Sheikh Formation in the north Delta embayment, as well as the shallow marine marls, sandstones and coquina limestones of Kom El Shelul Formation in the Nile Valley.

Kom El Shelul Formation:

Type section: Kom El Shelul, Pyramids Plateau, Giza

Lithology: Sandstone and coquina limestone beds

Limits: Overlies unconformably the Upper Eocene Maadi Formation and underlies unconformably the Idfu Gravels.

Extent: Nile Valley from Cairo to Beni Suef.

Fossils: *Chlamys scabrella, Strombus coronaturs, Clypeaster aegyptiacus,* forams and ostracodes

Reference: SAID (1962)

Late Pliocene:

The river now in its Paleonile stage advanced along its valley cascading over the southern Delta block into a bay of the sea; brackish organisms appear there. The Paleonile has contributed more sediments than the other stages; its water sources came from vegetation coverd regions in the south e.g. from the now dry Wadis Milik, Hower and other sources from the Sudan. The Paleonile sediments crop out along the foot-slopes of the bounding cliffs of the present major wadies that drain into southern reaches of the Egyptian Nile indicating that these wadies (e.g. W. Qena, W. El Madamud, W. Kharit-Garara) were not only in existence when the Paleonile started flowing but that they also represented major tributaries of this river. The Paleonile sediments include the fluvial Madamud Formation in the Nile Valley, the Fluvio-marine upper part Kafr El

Sheikh Formation in the Nile Delta subsurface and the delatic beds of Gar El Meluk Formation in Wadi Natrun.

Gar El Meluk Formation:

Type section: Gar El Meluk hill, Wadi Natrun depression.

Lithology: A 35 m section of sand and shale with few limestone bands.

Fossils: *Saccostrea cucullata* in the lower level, fluvio-marine vertebrates (Crocodilian & fish remains) and ostracodes in the upper levels.

Reference: SAID (1981).

Madamud Formation:

Type section: Wadi Madamud, east bank, Qena province.

Lithology: Brown marls and rhythmically banded fine sand-silt laminae

Limits: Overlies older bedrock and underlies the Armant Formation.

Extent: Many wadies draining into the Nile from the Eastern Desert.

Fossils: Nonfossiliferous, coeval with Helwan Formation.

Reference: SAID (1981)

Pleistocene:

In the advent of the Pleistocene great tectonic and climatic events took place. This was an epoch of high seismicity in Egypt and the Red Sea area. The previous connections with southern water supplies were severed. The margin of the African continent was probably in mid-Delta. The deposits of the Paleonile/Protonile interval (1.85 mill. years - 700,000 years BP) are represented by the Armant and the Issawia formations of Early Pleistocene age.

Armant Formation:

Type section: Wadi Bairriya, opposite Armant, Luxor district.

Lithology: Locally derived gravels alternating with fine grained clastics.

Limits: Overlies older bedrock and underlies Qena Formation.

Extent: Many wadis drain into the Nile in Upper Egypt.

Fossils: Nonfossiliferous.

Reference: Said (1975).

Issawia Formation:

Type section: Issawia quarry, Akhmim, Upper Egypt.

Lithology: Bedded travertines with minor conglomerate lenses.

Extent: Nile Valley in its middle latitudes.

Limits: Overlies the Armant Formation.

Fossils: Unidentified reeds and stems

Reference: SAID (1975)

The Protonile (700,000 - 500,000 BP) had a more western course than the present river with sediments of gravel and sand in terraces parallel to the modern Nile Valley. Water sources of this Nile were mainly from outside Egypt but the Red Sea hills also contributed via the Wadi Alaqi, Kharit and Gabgaba. The Protonile deposits are well represented in the Idfu Gravels of Early Pleistocene age.

Idfu Formation:

Type section: Wadi El Hassayia, Darb El Gallaba plain, Idfu west, Upper Egypt.

Lithology: Chert gravels and quartzose sands in a red-brown matrix.

Extent: Along the western banks of the Nile and Delta.

Fossils: Nonfossiliferous but archaeologically sterile.

Reference: SAID (1975).

The Prenile (500,000 - 125,000 BP) was a strong river with large floods after the connection with the Atbra, contemporaneous with the Riss glaciation. A large delta was created with sediments extending into the sea. The sediments were estimated as twice as big as those present. They are represented by the Qena sediments of Middle Pleistocene age.

Qena Formation:

Type locality: Wadi Abu Manaa, east bank of Dishna, Qena province.

Lithology: Cross bedded fluvial sands with minor conglomerates.

Limits: Overlies unconformably the Madamud Formation and underlies unconformably the Abbassia Gravels.

Extent: Nile Valley, Delta edges and the Fayoun Depression.

Fossils: African molluscans as *Unio abyssinicus,* etc... and some late Acheulean implements.

Reference: SAID (1975)

The Pre-Neonile interval lasted from the above date to about 30,000 BP when the Neonile began to flow. In the early part of the interval, corresponding with the Würm II, there were considerable rainfalls with gravel deposits resulting. At Abbassia, north-east Cairo, the first prehistoric remains of man of late Acheulean age were found in 1920. Some gravels had also Red Sea hills origin. This pluvial phase was followed by arid conditions contemporaneous with Würm I. Prenile sediments were cut dowm and the final shape of the present Nile Valley was formed.

Abbassia Formation:

Type section: Half way along the Fayoum-Wasta railway line.

Lithology: Polygenetic rounded gravels.

Limits: Overlies unconformably the Qena sands.

Extend: Nile Valley and Delta edges.

Fossils: Abundant late Acheulean hand axes

Reference: SAID (1975)

The Neonile is the best studied phase with considerable documentation from radiocarbon dates; tectonic events in Ethiopia occurred still and the climate was arid with some fluctuations. The Neonile deposits are made up of four units of aggradational deposits formed by four rivers, the α, β, γ and δ Neoniles separated by three recessions. The Neonile deposits are divided into three major units which are from top to bottom:

3. The Younger Neonile deposits including the deposits of the δ Neonile and the preceding recessional deposits; Arkin and Dishna-Ineiba, respectively.

2. The older Neonile deposits including the deposits of the γ Neonile (Sahaba-Darau), the β Neonile (Masmas-Ballana) and the intervening recession (Deir El Fakhuri).

1. The basal Neonile deposits including the deposits of the α (Dandara) and the α/β recession (made up the deposits of the arid Gerza-Ikhtiariya and wet Korosko-Makhadma episodes. The conglomerates below and above the Dandara silts are called Abbassia I and II, respectively. The age of the deposits is Late Pleistocene to Recent.

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Era	Sub-era / Period / Sub-period	Epoch	Age	Ma age	Age abbrev.	Ma intervals	
Cenozoic Cz	Quaternary or Pleistogene	Holocene		0·01	Hol	·01	2
		Pleistocene		2·0	Ple	1·99	
	Tertiary Tt, Neogene Ng	Pliocene 2	Piacenzian		Pia	3·1	22·6
		1	Zanclian	5·1	Zan		
		Miocene 3	Messinian		Mes	6·2	
			Tortonian		Tor		
		2	Serravallian		Srv	3·1	
			Langhian-Late		Lan2		
			Langhian-Early	14·4	Lan1	10·2	
		1	Burdigalian		Bur		
			Aquitanian	24·6	Aqt		
	Paleogene Pg	Oligocene 2	Chattian	32·8	Cht	8·2	40·4
		1	Rupelian	38·0	Rup	5·2	
		Eocene 3	Priabonian	42·0	Prb	4	
		2	Bartonian		Brt	8·5	
			Lutetian	50·5	Lut		
		1	Ypresian	54·9	Ypr	4·4	
		Paleocene 2	Thanetian	60·2	Tha	5·3	
		1	Danian	65	Dan	4·8	
Mesozoic Mz	Cretaceous K	K_2 Senonian	Maastrichtian	73	Maa	8	79
			Campanian	83	Cmp	10	
			Santonian	87·5	San	4·5	
			Coniacian	88·5	Con	1	
			Turonian	91	Tur	2·5	
			Cenomanian	97·5	Cen	6·5	
		K_1	Albian	113	Alb	15·5	
			Aptian	119	Apt	6	
			Barremian	125	Brm	6	
		Neocomian	Hauterivian	131	Hau	6	
			Valanginian	138	Vlg	7	
			Berriasian	144	Ber	6	
	Jurassic J	Malm J_3	Tithonian	150	Tth	6	69
			Kimmeridgian	156	Kim	6	
			Oxfordian	163	Oxf	7	
		Dogger J_2	Callovian	169	Clv	6	
			Bathonian	175	Bth	6	
			Bajocian	181	Baj	6	
			Aalenian	188	Aal	7	
		Lias J_1	Toarcian	194	Toa	6	
			Pliensbachian	200	Plb	6	
			Sinemurian	206	Sin	6	
			Hettangian	213	Het	7	
	Triassic Tr	Tr_3	Rhaetian	219	Rht	6	35
			Norian	225	Nor	6	
			Carnian	231	Crn	6	
		Tr_2	Ladinian	238	Lad	7	
			Anisian	243	Ans	5	
		Scythian Tr_1	Spathian		Spa	1¼	
			Smithian		Smi	1¼	
			Dienerian		Die	1¼	
			Griesbachian	248	Gri	1¼	
Paleozoic	Permian P	P_2	Tatarian	253	Tat	5	38
			Kazanian		Kaz	2·5	
			Ufimian	258	Ufi	2·5	
		P_1	Kungurian	263	Kun	5	
			Artinskian	268	Art	5	
			Sakmarian		Sak	9	
			Asselian	286	Ass	9	
	Carboniferous, Pennsylvanian C_2	Gzelian	Noginskian		Nog		34
			Klazminskian		Kla		
		Kasimovian	Dorogomilovsk.		Dor		
			Chamovnichesk.		Chv		
			Krevyakinskian		Kre		
		Moscovian	Myachkovskian	296	Mya		
			Podolskian		Pod		
			Kashirskian		Ksk		
			Vereiskian		Vrk		
		Bashkirian	Melekesskian		Mel		
			Cheremshansk.	315	Che		
			Yeadonian		Yea		
			Marsdenian		Mrd		
			Kinderscoutian	320	Kin		
	C_1	Serpukhovian	Alportian		Alp		40
			Chokierian		Cho		

Era	Sub-era / Period / Sub-per.	Epoch	Age	Ma age	Age abbrev.	Ma intervals	
Paleozoic Pz	Carboniferous C, C_2	Bashkirian	Marsdenian		Mrd		34
			Kinderscoutian	320	Kin		
	Mississippian C_1	Serpukhovian	Alportian		Alp	13	40
			Chokierian		Cho		
			Arnsbergian		Arn		
			Pendleian	333	Pnd		
		Visean	Brigantian		Bri	19	
			Asbian		Asb		
			Holkerian		Hlk		
			Arundian		Aru		
			Chadian	352	Chd		
		Tournaisian	Ivorian		Ivo	8	
			Hastarian	360	Has		
	Devonian D	D_3	Famennian	367	Fam	7	48
			Frasnian	374	Frs	7	
		D_2	Givetian	380	Giv	6	
			Eifelian	387	Eif	7	
		D_1	Emsian	394	Ems	7	
			Siegenian	401	Sig	7	
			Gedinnian	408	Ged	7	
	Silurian S	Pridoli		414	Prd	6	30
		Ludlow	Ludfordian		Ldf	7	
			Gorstian	421	Gor		
		Wenlock	Gleedon		Gle	7	
			Whitwell		Whi		
			Sheinwoodian	428	She		
		Llandovery	Telychian		Tel	10	
			Fronian		Fro		
			Idwian		Idw		
			Rhuddanian	438	Rhu		
	Ordovician O_3	Ashgill	Hirnantian		Hir	10	67
			Rawtheyan		Raw		
			Cautleyan		Cau		
			Pusgillian	448	Pus		
		Caradoc	Onnian		Onn	10	
			Actonian		Act		
			Marshbrookian		Mrb		
			Longvillian		Lon		
			Soudleyan		Sou		
			Harnagian		Har		
			Costonian	458	Cos		
	O_2	Llandeilo	Late		Llo_3	10	
			Middle		Llo_2		
			Early	468	Llo_1		
		Llanvirn	Late		Lln_2	10	
			Early	478	Lln_1		
	O_1	Arenig		488	Arg	10	
		Tremadoc		505	Tre	17	
	Cambrian €	Merioneth	Dolgellian		Dol	9	85
			Maentwrogian	523	Mnt	9	
		St David's	Menevian		Men	9	
			Solvan	540	Sol	8	
		Caerfai	Lenian		Len	15	
			Atdabanian		Atb	15	
			Tommotian	590	Tom	20	
Sinian Z	Vendian V	Ediacaran	Poundian		Pou	40	80
			Wonokian	630	Won		
		Varangian	Mortensnes	650	Mor	20	
			Smalfjord	670	Sma	20	
	Sturtian U			800			
Riphean R				1050			
	Yurmatin Y			1350			
	Burzyan B			1650			
				2100			
Huronian H				2400			
				2630			
Randian Ran				2800			
Swazian Sw				3750			
Isuan I				3900			
Hadean Hde							

Harland, Cox, Llewellyn, Pickton, Smith, Walters 1982
A geologic time scale
Cambridge University Press

GEOLOGIC TIME SCALE

CENOZOIC

Period		Epoch / Stage			Age Ma
QUATERNARY		Holocene			0.01
QUATERNARY		Pleistocene		Calabrian	1.64
TERTIARY	NEOGENE	Pliocene	L	Piacenzian	3.40±1.35
TERTIARY	NEOGENE	Pliocene	E	Zanclian	5.2 ± 1.5
TERTIARY	NEOGENE	Miocene	L	Messinian	6.7 ± 2.3
TERTIARY	NEOGENE	Miocene	L	Tortonian	10.4 ± 1.5
TERTIARY	NEOGENE	Miocene	M	Serravallian	14.2 ± 1.8
TERTIARY	NEOGENE	Miocene	M	Langhian	16.3 ± 1
TERTIARY	NEOGENE	Miocene	E	Burdigalian	21.5 ± 1.8
TERTIARY	NEOGENE	Miocene	E	Aquitanian	23.3 ± 1
TERTIARY	PALEOGENE	Oligocene	L	Chattian	29.3 ± 1.5
TERTIARY	PALEOGENE	Oligocene	E	Rupelian	35.4 ± 1.4
TERTIARY	PALEOGENE	Eocene	L	Priabonian	38.6 ± 1.5
TERTIARY	PALEOGENE	Eocene	M	Bartonian	42.1 ± 1.8
TERTIARY	PALEOGENE	Eocene	M	Lutetian	50 ± 1.5
TERTIARY	PALEOGENE	Eocene	E	Ypresian	56.5 ± 1.4
TERTIARY	PALEOGENE	Paleocene	L	Thanetian	60.5 ± 2.3
TERTIARY	PALEOGENE	Paleocene	E	Danian	65 ± 2

MESOZOIC

Period		Epoch / Stage	Age Ma
CRETACEOUS	L		65.0 ± 2
CRETACEOUS	L	Maastrichtian	74.0 ± 3
CRETACEOUS	L	Campanian	83 ± 4
CRETACEOUS	L	Santonian	86.6 ± 3
CRETACEOUS	L	Coniacian	88.5 ± 2
CRETACEOUS	L	Turonian	90.4 ± 2
CRETACEOUS	L	Cenomanian	97.0 ± 2
CRETACEOUS	E	Albian	112 ± 2
CRETACEOUS	E	Aptian	124.5 ± 13
CRETACEOUS	E	Barremian	131.8 ± 8
CRETACEOUS	E	Hauterivian	135.0 ± 8
CRETACEOUS	E	Valanginian	140.7 ± 13
CRETACEOUS	E	Berriasian	144.8 ± 3.1
JURASSIC	L	Tithonian	151.5 ± 1.2
JURASSIC	L	Kimmeridgian	154.7 ± 1.0
JURASSIC	L	Oxfordian	156.6 ± 2.3
JURASSIC	M	Callovian	159.7 ± 0.5
JURASSIC	M	Bathonian	166.0 ± 1.1
JURASSIC	M	Bajocian	174.0 ± 4.1
JURASSIC	M	Aalenian	178 ± 1.5
JURASSIC	E	Toarcian	183.6 ± 1.5
JURASSIC	E	Pliensbachian	192.0 ± 4.5
JURASSIC	E	Sinemurian	197.0 ± 2.7
JURASSIC	E	Hettangian	199.6 ± 0.7
TRIASSIC	L	Norian	223.4 ± 9.5
TRIASSIC	L	Carnian	235 ± 4
TRIASSIC	M	Ladinian	239.5 ± 6.5
TRIASSIC	M	Anisian	241.1 ± 8
TRIASSIC	E	Spathian	(242)
TRIASSIC	E	Smithian	(243)
TRIASSIC	E	Dienerian	(244)
TRIASSIC	E	Griesbachian	251 ± 0.4

PALEOZOIC

Period			Epoch / Stage	Age Ma
PERMIAN		L	Changxingian	251 ± 0.4
PERMIAN		L	Longtanian	255
PERMIAN		L	Capitanian	264
PERMIAN		L	Wordian / Roadian	258.0 ± 7
PERMIAN		E	Artinskian	269 ± 11
PERMIAN		E	Sakmarian	281.5 ± 13
PERMIAN		E	Asselian	290 ± 9
CARBONIFEROUS	PENNSYLVANIAN	L	Gzhelian	295 ± 6.5
CARBONIFEROUS	PENNSYLVANIAN	L	Kasimovian	303 ± 5
CARBONIFEROUS	PENNSYLVANIAN	L	Moscovian	311.5 ± 9.5
CARBONIFEROUS	PENNSYLVANIAN	L	Bashkirian	323 ± 9
CARBONIFEROUS	MISSISSIPPIAN	E	Serpukhovian	333 ± 8
CARBONIFEROUS	MISSISSIPPIAN	E	Visean	349.5 ± 4.5
CARBONIFEROUS	MISSISSIPPIAN	E	Tournaisian	362
DEVONIAN		L	Famennian	376.5
DEVONIAN		L	Frasnian	382.5
DEVONIAN		M	Givetian	387.5
DEVONIAN		M	Eifelian	394
DEVONIAN		E	Emsian	409.5
DEVONIAN		E	Pragian	413.5
DEVONIAN		E	Lochkovian	418
SILURIAN		L	Pridolian	419
SILURIAN		L	Ludlovian	423
SILURIAN		E	Wenlockian	428
SILURIAN		E	Llandoverian	443
ORDOVICIAN		L	Ashgillian	449
ORDOVICIAN		L	Caradocian	458
ORDOVICIAN		M	Llandeilian	464
ORDOVICIAN		M	Llanvirnian	470
ORDOVICIAN		E	Arenigian	485
ORDOVICIAN		E	Tremadocian	495
CAMBRIAN		Late		505
CAMBRIAN		Middle		518
CAMBRIAN		E	Toyonian	522
CAMBRIAN		E	Botomian	525
CAMBRIAN		E	Atdabanian	528
CAMBRIAN		E	Tommotian	531.0 ± 1.0
CAMBRIAN		E	Nemakit - Daldynian	543.9 ± 1.0

1) W.B.Harland et al., 1990 - Phanerozoic
2) Lumbers & Card (Geology Vol. 20, 1991) - PreCamb.
3) R.D. Tucker & W.S. McKerrow, 1995 - Ord.-Sil.
4) R.D. Tucker et al. 1998 - Devonian
5) Pally et al., 1996 - Jurassic
6) S.A. Bowring & D.H. Erwin, 1998 - Permo-Triassic

PRECAMBRIAN

Eon	Era		Period	Age Ma
PROTEROZOIC	Hadrynian (late)	Neoproterozoic	Ediacaran	543.9 ± 1.0
PROTEROZOIC	Hadrynian (late)	Neoproterozoic	Varangian	565
PROTEROZOIC	Hadrynian (late)	Neoproterozoic	Cryogenian	605
PROTEROZOIC	Hadrynian (late)	Neoproterozoic	Tonian	850
PROTEROZOIC	Helikian (middle)	Mesoproterozoic	Stenian	1000
PROTEROZOIC	Helikian (middle)	Mesoproterozoic	Ectasian	1200
PROTEROZOIC	Helikian (middle)	Mesoproterozoic	Calymmian	1400
PROTEROZOIC	Aphebian (early)	Paleoproterozoic	Statherian	1600
PROTEROZOIC	Aphebian (early)	Paleoproterozoic	Orosirian	1800
PROTEROZOIC	Aphebian (early)	Paleoproterozoic	Rhyacian	2050
PROTEROZOIC	Aphebian (early)	Paleoproterozoic	Siderian	2300
ARCHEAN	Neoarchaean (late)			2500
ARCHEAN	Mesoarchaean (middle)			2800
ARCHEAN	Paleoarchaean (early)			3200
ARCHEAN	Eoarchaean (earliest)			3600
			base not defined	~4500 Ma

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